A HYDROGRAPHIC AND ACOUSTIC SURVEY OF THE PERSIAN GULF - PART I

Jay Lee Wright

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A HYDROGRAPHIC AND ACOUSTIC SURVEY
OF THE PERSIAN GULF - PART I

by

Jay Lee Wright

September 1974

Thesis Advisor: R. H. Bourke

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A Hydrographic and Acoustic Survey of the Persian Gulf - Part I

by

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Lieutenant, United States Navy
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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

A survey of literature and historical data is utilized to investigate the seasonal variations in the hydrographic and acoustic properties of the Persian Gulf.

The Gulf has a year round salinity of about 40 o/oo. The surface temperature varies from 30°C in summer to 20°C in winter. An area of significant importance in the Gulf is near the Strait of Hormuz where the Persian Gulf water encounters the warmer less saline water of the Arabian Sea.

Utilizing the FACT acoustic transmission loss model, detection ranges for diesel and nuclear submarines are investigated. Generally, ranges appear to be greater in winter due to increased vertical mixing, creating strong positive sound speed gradients.

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I. INTRODUCTION

It has been proposed that in 1975 the Naval Underwater System Center with the assistance of the Naval Postgraduate School, conduct a hydrographic and acoustic survey of the Persian Gulf. The purpose of this cruise will be to prepare a report for the Shah of Iran on sound propagation conditions within the Gulf applicable to specific sound surveillance systems.

This thesis is submitted as a pre-cruise report to aid NUSC in planning the expedition. The objectives of the thesis are: 1) to provide a survey of the literature, consolidating relevant material into a single reference; 2) to report on the hydrographic structure of the Gulf, using historical data; and 3) to report on sound propagation conditions in the Gulf, based on the hydrographic structure. Hopefully, realization of these objectives will enable NUSC to determine areas in the Gulf where study should be concentrated.

II. LITERATURE SURVEY

A. AREA DESCRIPTION

1. Political

Only in recent years has the importance of the Persian Gulf region come to the attention of the general public, this resulting mainly from the highly journalized oil export practices of the Gulf countries. The United States Government in recognizing the strategic importance of the Gulf region as a source of petroleum has been vitally interested in maintaining a friendly relationship with the one politically neutral country bordering the Gulf, Iran.

Iran has become immensely wealthy through its oil industry, and under the strong leadership of Shah Mohammed Reza Pehlavi, it is emerging rapidly as the key to stability in this area of the world. Because Iran maintains friendly relations with both the United States and the Soviet Union, it enjoys the technical assistance and material support of both nations. In particular the United States is providing current weapons platforms, such as the F-14 and P-3 aircraft, and the Spruance class destroyer. Furthermore, the proposed NUSC cruise will be undertaken at the request of the Shah, who has recognized that in order for Iran to assert itself as the "peace keeper" of the Persian Gulf, it must have a thorough understanding of the ocean environment to make optimum use of new weapons platforms.

2. Geographical

The Persian Gulf is a shallow basin 500 miles (311 km) long by 200 miles (124 km) wide which separates the Arabian Plateau from Iran. Its deepest channel, seldom deeper than 50 fathoms (91 m) lies close to the Iranian shore. Along the coastal areas of the Gulf there is scant vegetation, a result of a meager annual rainfall of only 3 to 11 inches (7.6 to 28.0 cm) most of which falls during the winter months. Temperatures averaging 90°F (33°C) and exceeding 120°F (48°C) in some locations are common during the summer months. During the winter season temperatures are cooler averaging 70°F (21°C), with nighttime lows of 40°F (5°C) in the western part of the Gulf.

Viewed from Iran, the Persian Gulf appears as a remote region, kept inaccessible by the vast arc of the Zargos Mountains (Figure 1). Only in the northern part of the Gulf, where Iran's oil-rich Khuzestan plain merges with the Shatt-al-Arab River to form a delta is the Gulf easily accessible. The 120 mile-long (75 km) Shatt-al-Arab River is formed by the confluence of the Tigris, Euphrates and Karun Rivers. It provides a waterway to the main port of Iraq at Basra. The Karun River, which joins the Shatt-al-Arab downstream from Basra provides access to the major Iranian ports of Khoiramshahr and Abadan. On the coast, northeast of the mouth of the Shatt-al-Arab, lie the Iranian sea ports, Mashur and Shapur. To the south lies the brief, open coast of Iraq.

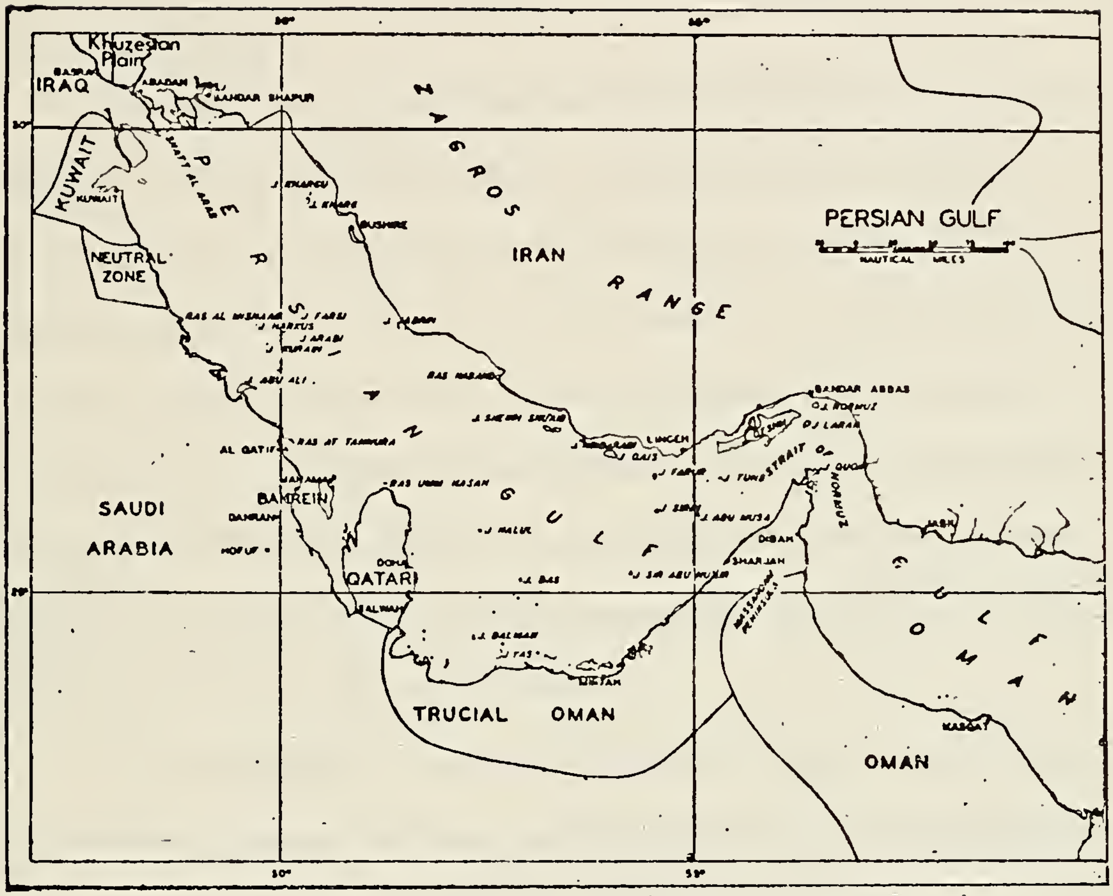

Figure 1. Persian Gulf with bordering countries and important cities (modified from Emery, 1956)

The western side of the Gulf is 1300 miles in length from the Shatt-al-Arab to Oman on the Musandam Peninsula. The coast line is ill defined in this region and navigation is hazardous due to the presence of numerous shoals, reefs, and islands.

4. Hydrology

Although the Persian Gulf acts as the drainage center for most of Arabia, all of Iraq, parts of Syria, Turkey and Iran, little fresh water flows into the Gulf except at the northern end via the Shatt-al-Arab River [Sugden, 1963]. This inflow amounts to about 45 cubic kilometers per year, most of which occurs during the flooding season (January-March). Flow rates during the flood season are affected by the yearly variation of rainfall. For example, in 1929 the maximum flood discharge rate of the Euphrates River was 4,700 m^3/sec, while in 1930 the rate was only 650 m^3/sec.

Occasionally there is an additional fresh water input along the coast of Iran as a result of flood discharge during the winter [Sugden, 1963].

B. RELEVANT OCEANOGRAPHIC CHARACTERISTICS

5. Temperature, Salinity, Density and Circulation

During the summer Emery [1956] found a general increase in sea surface temperatures from 75°F (24°C) in the Arabian Sea to more than 92°F (33°C) in the Persian Gulf. Temperatures of the winter are far different from those of summer, with values of only 60°F (16°C) at

the head of the Gulf, increasing to about 75°F (24°C) in the Arabian Sea. Thus the water at the head of the Gulf undergoes an annual change of at least 30°F (17°C) [Emery, 1956].

The summer surface salinity increases from about 36.5 o/oo in the Gulf of Oman to over 42 o/oo in the Persian Gulf. Winter salinities in the Gulf of Oman differ little from their summer time value. The Persian Gulf, on the other hand, is diluted in winter by the increased flow of the Shatt-al-Arab River and therefore has a salinity of 40 o/oo or less [Emery, 1956].

The Gulf is similar to a land-locked sea in which evaporation exceeds precipitation [Sverdrup, Johnson and Fleming, 1942]. The water loss due to evaporation is made up by the inflow of water from the open ocean through the Strait of Hormuz. This water moves on the surface toward the Gulf's coastal margins gradually increasing in density. Eventually the water sinks to lower levels where it flows out of the Gulf below the incoming water. Figure 2 is a schematic of this density driven circulation [Sugden, 1963]. Summer in the Gulf is substantially hotter than the winter, but the differences between summer and winter surface salinities are not great; hence, evaporation evidently continues at a high rate throughout the year [Sugden, 1963]. The control of density by salinity is, of course, modified by temperature changes which vary in effect according to the seasons. However, salinity, as opposed to temperature, is a much more important determinant of density than in the open ocean [Sugden, 1963].

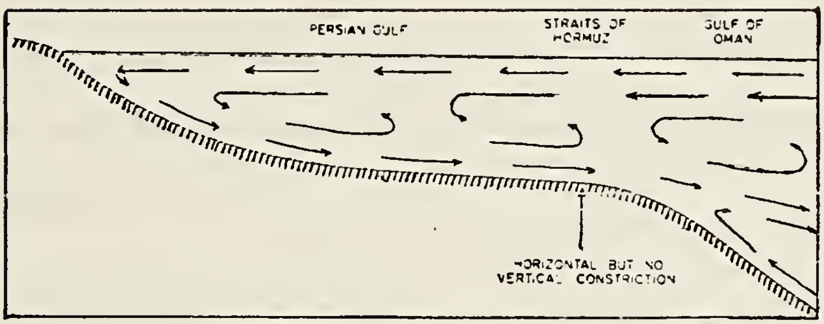

Figure 2. Diagramatic representation of water circulation in the Persian Gulf (Sugden, 1963)

III. HYDROGRAPHIC INVESTIGATION

A. SOURCE OF DATA

The National Oceanographic Data Center, NODC, provided all known temperature and salinity observations for the Persian Gulf, which consisted of bathythermograph and hydrographic observations. Only hydrographic data were used in this thesis. Specifically, only values of temperature, salinity and sound speed, as calculated by Wilson's equations, were utilized. The data were converted to printed output and punched cards through the use of an existing FORTRAN program utilizing the Naval Postgraduate School IBM 360 Computer (Appendix A).

B. PREPARATION OF DATA

In order to make optimum use of the data the Gulf was divided into 1° (one degree) squares, with 60°E as the eastern boundary, thus including the Strait of Hormuz and the Gulf of Oman in this study. Further, since a seasonal description of the oceanographic character of the Gulf was desired, two months from each of the primary seasons, winter and summer, were chosen for investigation. The months of January and February were chosen as characteristic of winter conditions while July and August were chosen for summer. After sorting the data, as described above, it became obvious that there is a paucity of data from

the Persian Gulf area. Figure 3 shows a plot of the monthly distribution for each one degree square. The number of observations in the squares vary from 100 to 0. The data were concentrated to some degree within the months of February and July; therefore, the other months were eliminated from further consideration. Figure 4 entitled, "Confidence Level" assigns an arbitrary value of good, fair or poor according to how many observations are in each square for February or July.

The next step in the data preparation was to perform a statistical analysis of the data for February and July. The monthly mean temperature, salinity, and sound speed were determined at standard depths for each 1^{o} square. As the data were sparse for most 1^{o} squares, the mean was the only meaningful statistic obtained. The resulting values of mean temperature, salinity and speed sound were used to investigate the hydrography of the Gulf.

C. APPLICATION OF DATA

Rather than describe the hydrographic character of each 1^{o} square within the Persian Gulf, the analysis has been concentrated on a transect located in the center and deeper portions of the Gulf which are considered more representative of areas in which ASW operations might be conducted. Figures 5 and 6 show the transect and the location of the associated data points for February and July. It is important to note that the positions of the data points in these figures are arbitrary because the values they represent are based on data taken throughout each 1^{o} square. Vertical

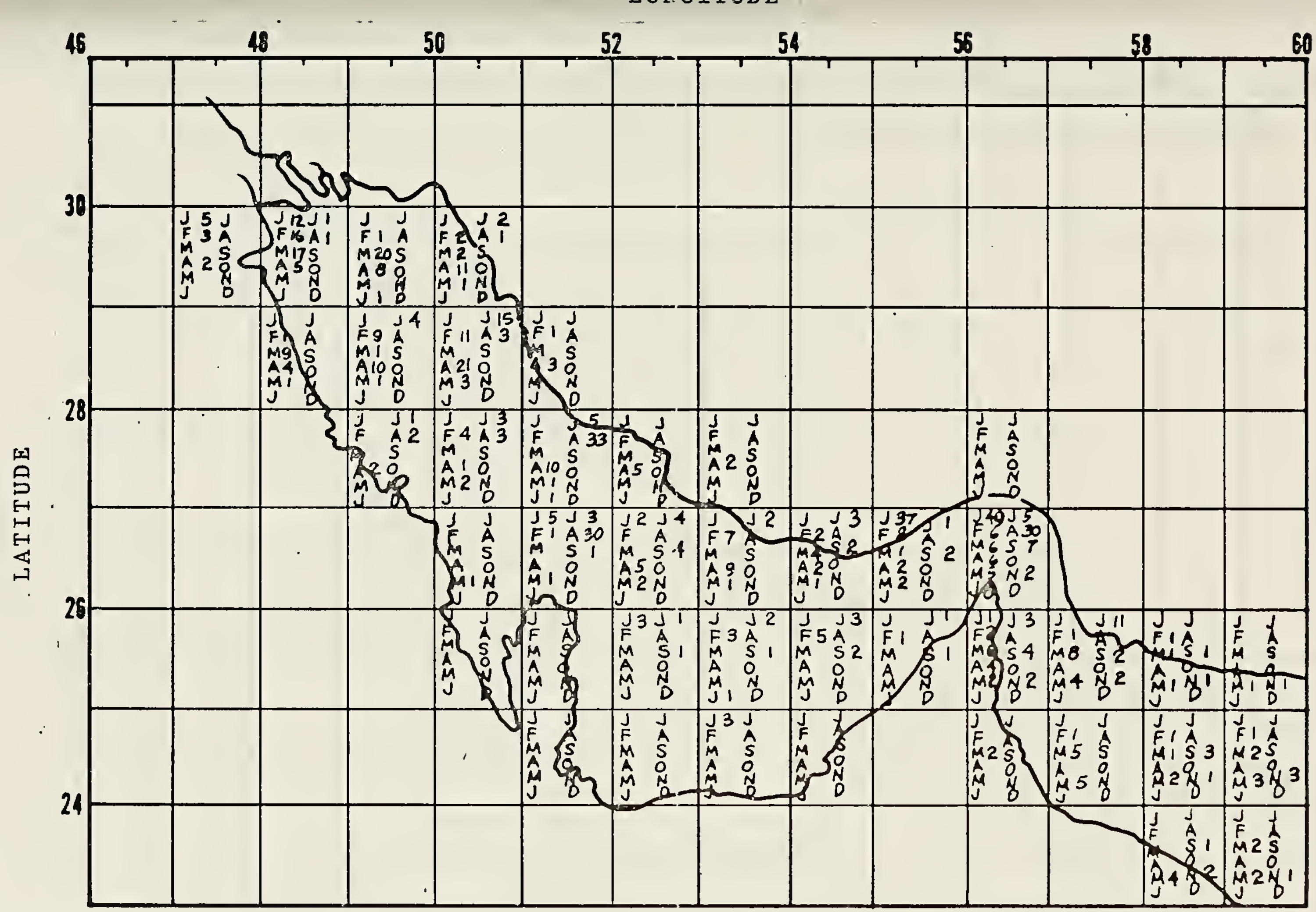

Figure 3. Distribution of all known hydrographic data by month for each 1^{o} square. Letters stand for month of year and numbers stand for observations.

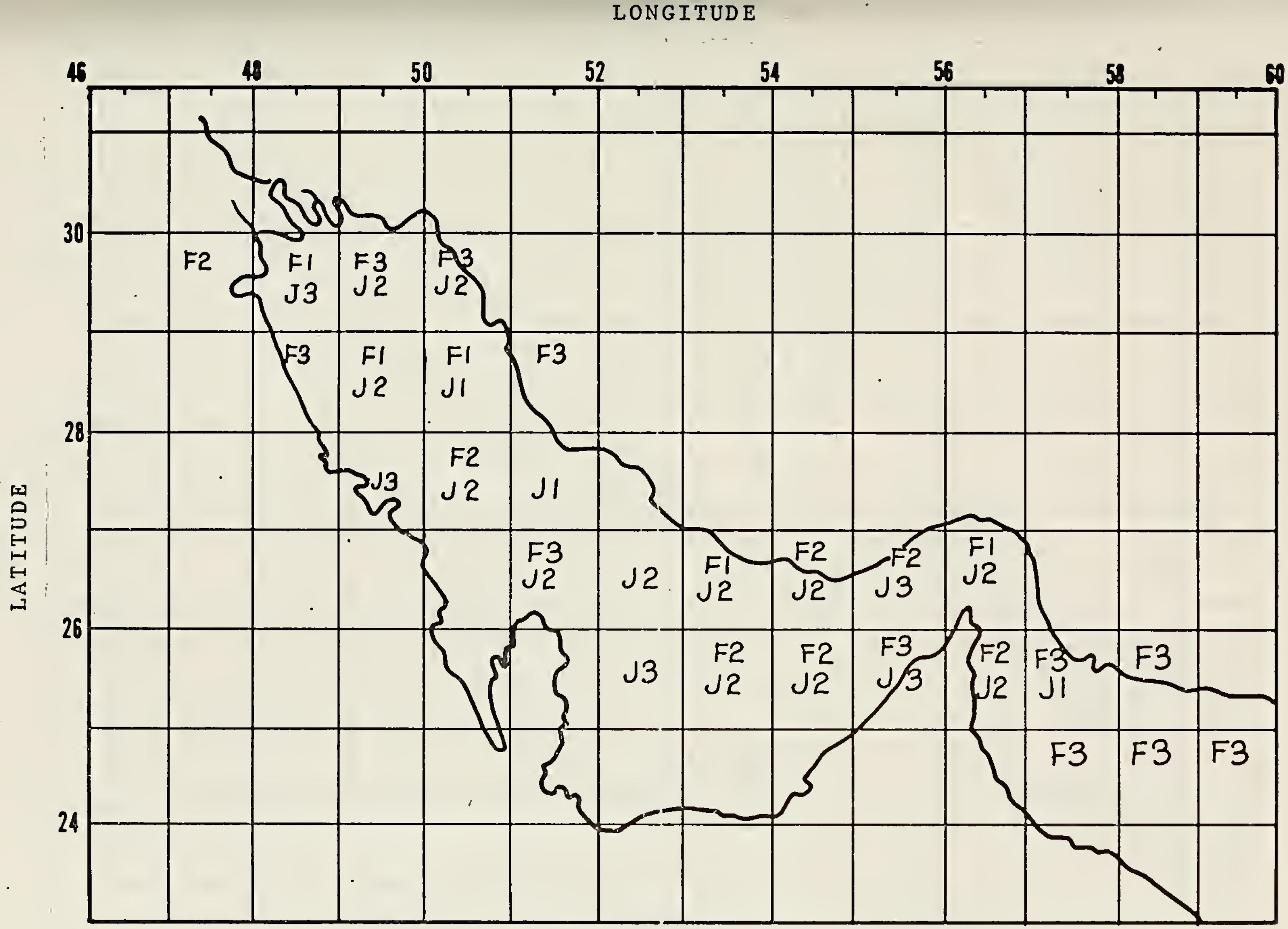

Figure 4. Confidence level based on the number of observations for the months of February and July. F= Feb. J= Jul. 1=good(> 5 obs). 2=fair(1< obs ≤ 5). 3=poor(1 obs).

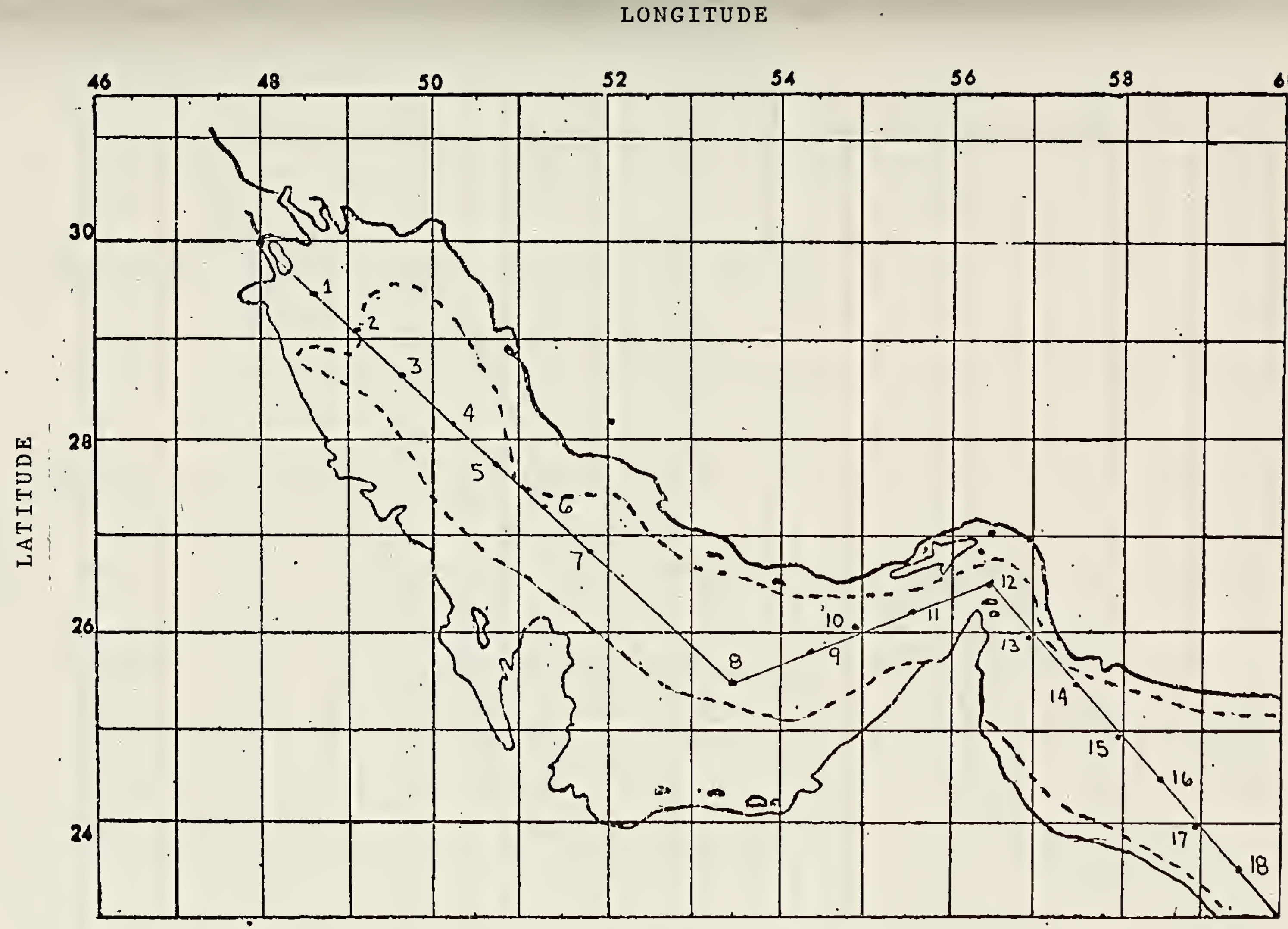

Figure 5. February transect and data points for the included 1^{o} squares. Dashed line is the 10 fathom curve.

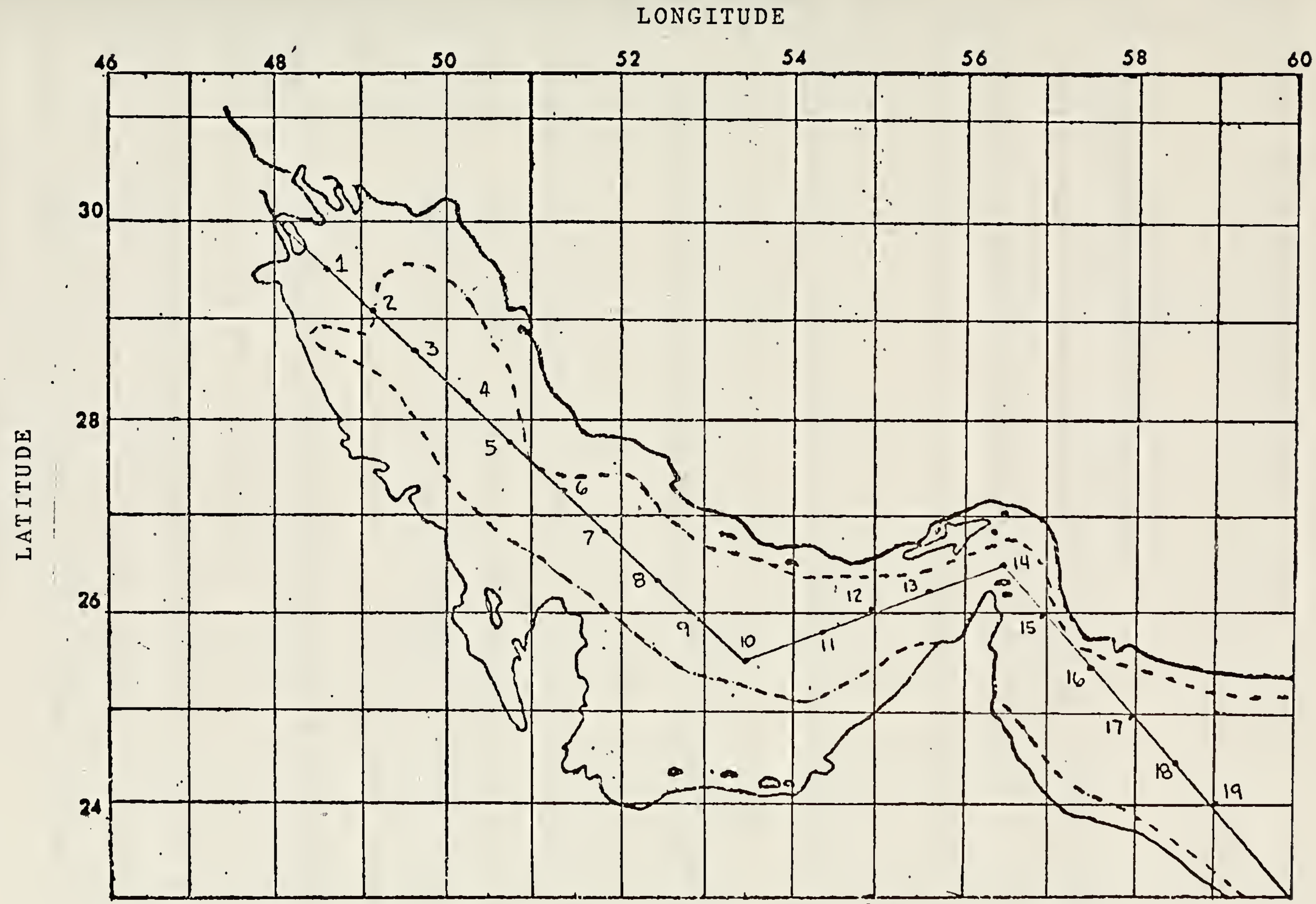

Figure 6. July transect and data points for the included 1° squares. Dashed line is the 10 fathom curve.

plots of mean temperature, salinity and sound speed for each of the 1° squares along the transect were then constructed. In order to establish the continuity of this technique verticle cross sections of temperature and salinity and a nested temperature-salinity plots were constructed.

D. ANALYSIS OF WINTER CONDITIONS

During winter the Gulf is affected by the influx of water from the Shatt-al-Arab River at the northwestern end of the Gulf (Figure 7). The cooling effect of the river is seen as far south as point 8, where the 20°C water underlies the 21°C water. This finding agrees with Sugden [1963], as he states that the river discharge can influence the temperature of the Gulf water at least as far south as 28°N, 50°E or near point 4.

The temperature generally decreases with depth until point 9. Between points 9 and 12 the temperature increases from about 22°C at the surface to 23°C at depth. The reason for this increase with depth is unclear. Emery [1956] found that in this area, between points 9 and 12, there is mixing between the warmer Arabian Sea water entering the Gulf, and the cooler Persian Gulf water, exiting the Gulf. However, the strong halocline which exists during winter in this area would prevent mixing below about 30 meters (Figure 13). As points 10 and 11 are based on only two observations taken by the same vessel during February of 1961, the 23°C temperature could be an anomalous condition or erroneous data. Since there are no other sources of water as warm as 23°C in the Gulf, the data are probably in error.

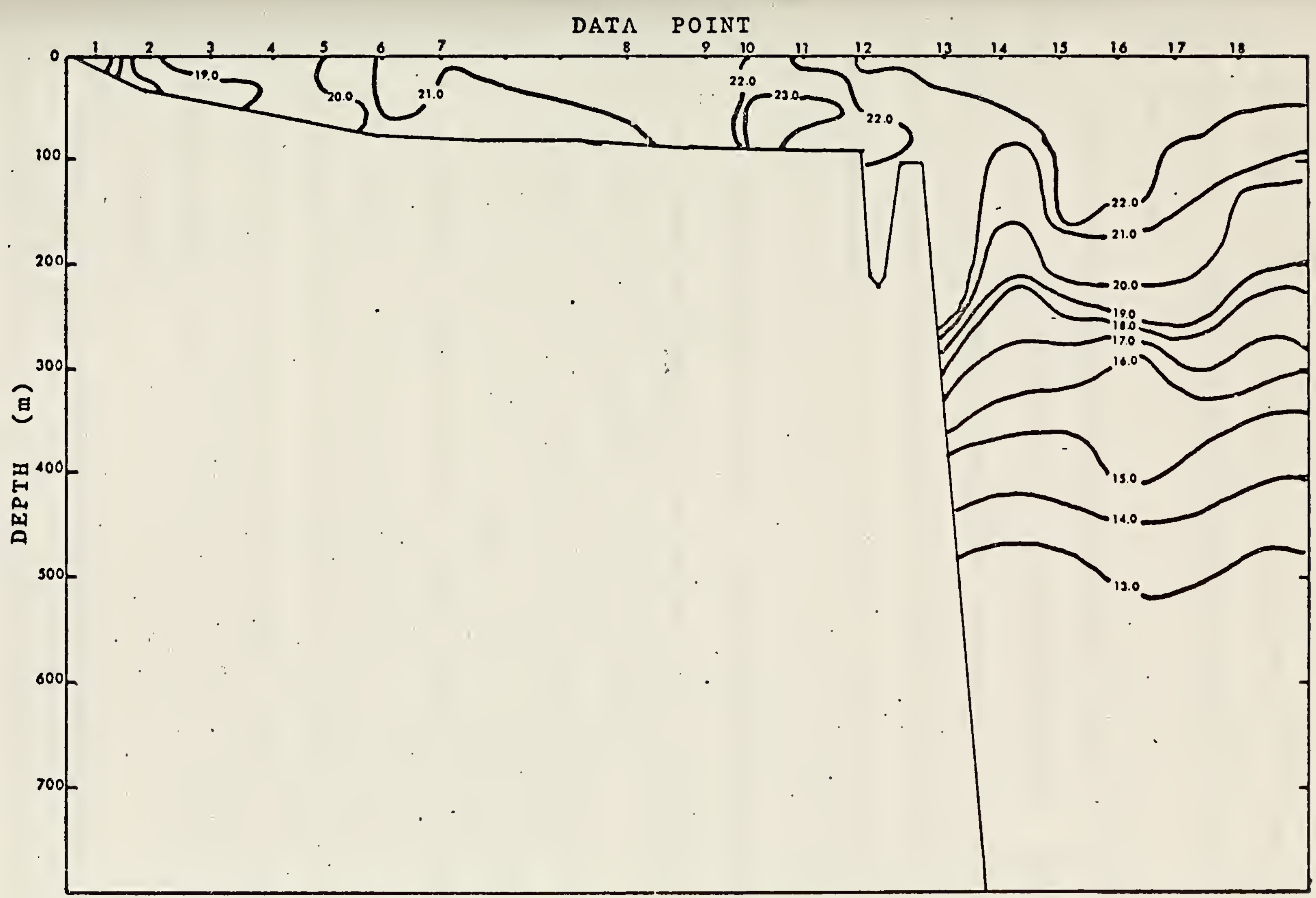

Figure 7. Vertical cross section of winter temperature (^{o}C) along the transect

The temperature between points 13 and 18 decreases from 22°C at the surface to 13°C at 500 meters. A warm nose of 22°C water can be seen at point 13, where the Persian Gulf water spills over the sill into the Gulf of Oman.

Figure 8 shows that the surface salinity decreases from 41 o/oo at the head of the Persian Gulf to 37 o/oo in the Gulf of Oman. This is contrary to Emery [1956]; however, it is in agreement with Schott's data of 1918. Both of these reports were based on single cruises indicating possible year-to-year variability. Salinity generally increases with depth at all locations until point 8. At points 8 and 9 the water column is nearly isohaline at 39 o/oo. This is indicative of a well mixed area, as is expected, since this is the region in which Arabian Sea water and Persian Gulf water encounter each other and mix.

The salinity increases with depth between points 10 and 13 from 37 o/oo at the surface to 39 o/oo at depth. This confirms the inflow of the lower salinity, Arabian Sea water at the surface and the outflow of the more saline, Persian Gulf water at the bottom. Further, at point 13 the Persian Gulf water can be followed over the sill in the Straits of Hormuz and down the slope into the Gulf of Oman. There it reaches an equilibrium depth between 200 and 300 meters, thus confirming what Emery [1956] found.

The winter picture is further clarified by examining the nested T-S diagram shown in Figure 9. At data points 1 through 7 the water column is approximately homogeneous with temperatures between 15°C and 20°C,

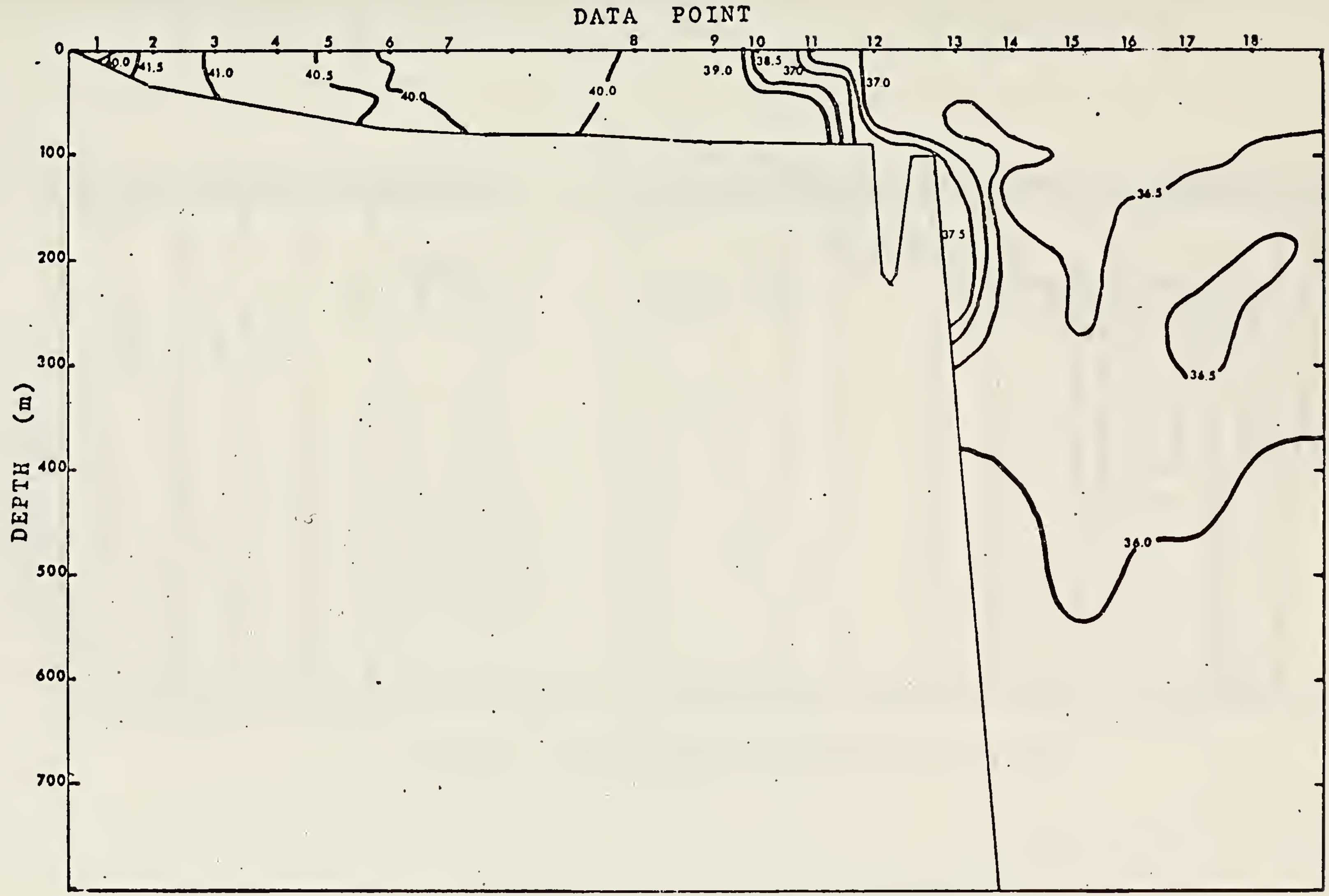

Figure 8. Vertical cross section of winter salinity (o/oo) along the transect

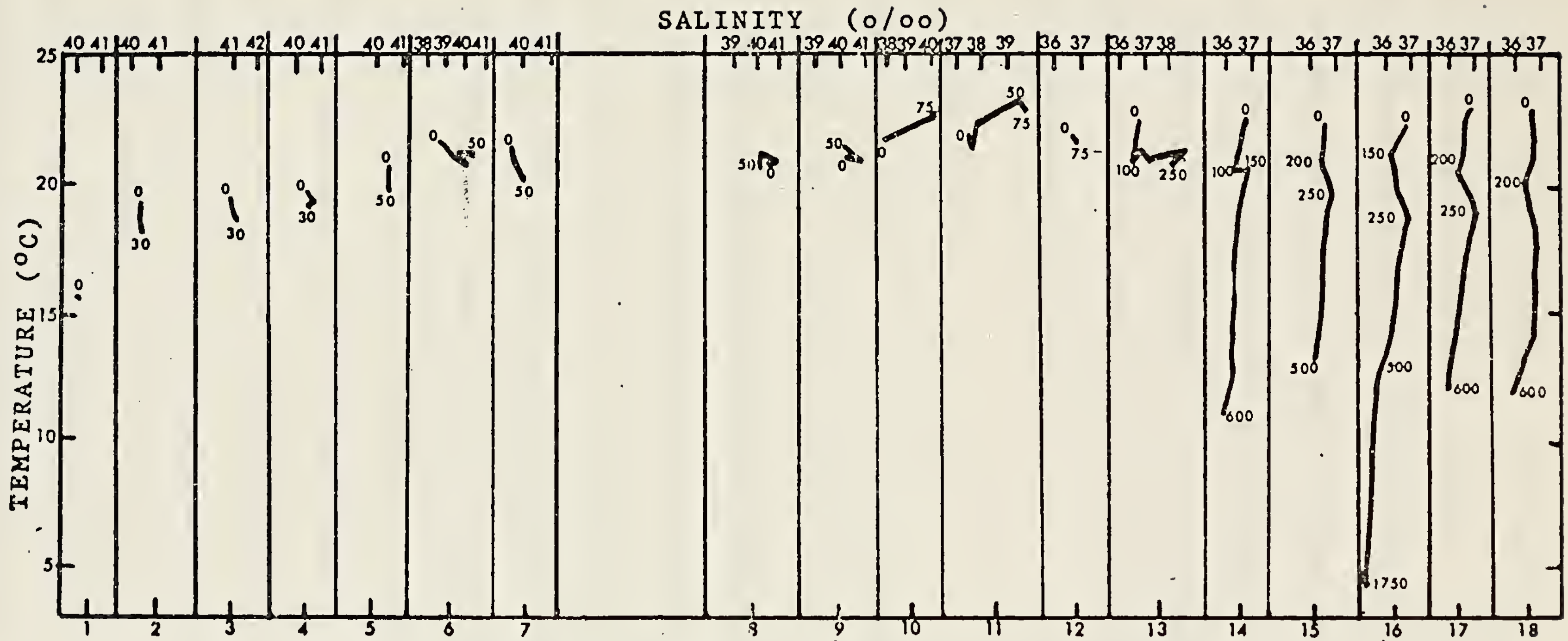

Figure 9. Nested winter T-S profiles along the transect

and salinities near 40o/oo to 41o/oo. The water column is also stable at these points as density increases with depth. The characteristic at points 8 and 9 is the instability of the water column at the surface changing to neutral stability at 50 meters. This further substantiates the idea that Arabian Sea water and Persian Gulf water mix in this region, however, only in the first 30 meters. Points 12 through 18 show the nose of the warmer, less saline Arabian Sea as it pushes into the Persian Gulf between the surface and about 200 m.

E. ANALYSIS OF SUMMER CONDITIONS

During summer the flow of the Shatt-al-Arab River is less than in the winter and the Gulf is relatively unaffected by the influx of water. The temperature is stratified throughout the Gulf, always decreasing with depth. There are several abnormally hot areas present, one of 32°C located at point 4 and a 30-32°C area located between points 13 and 16 (See Figure 10). These areas are similar to those found by Emery [1956]. The mean temperature for point 4 is based on 15 observations. However, the reason this point is relatively hot is unclear. The possibility that a majority of the observations were made in the nearshore portion of the 1° square was investigated and found to be invalid. Also a search of any reports of local heating phenomenon was conducted with no success.

The hot area in the vicinity of points 13 through 16 is in the region where Persian Gulf water and Arabian Sea water meet. During the summer months there appears to be little vertical mixing, and hence

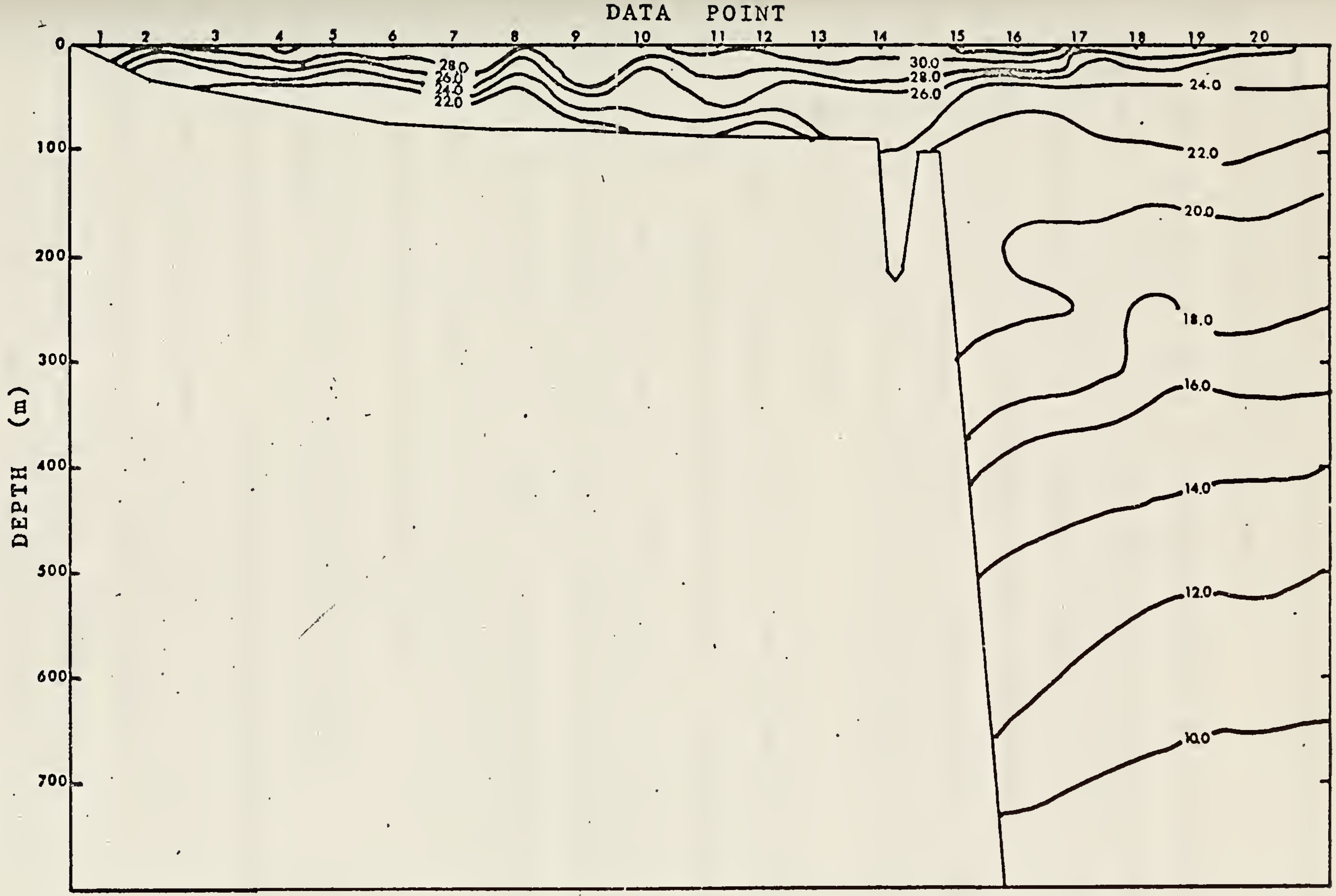

Figure 10. Vertical cross section of summer temperature (^{O}C) along the transect. Locations 17-20 are based on mean values for the month of May.

strong stratification occurs. A thin quiescent surface layer is formed which is heated considerably by insolation.

The salinity in summer is well stratified throughout the Gulf. A low salinity region of less than 39 o/oo is associated with the intrusion of the Shatt-al-Arab River at the extreme northwest end of the Gulf as depicted in Figure 11. As in winter, in the vicinity of the Strait of Hormuz, points 12 through 15, the 37-38 o/oo salinity nose of Persian Gulf water is observed to descend to about 300 m depth as it passes over the entrance sill of the Gulf.

The nested T-S diagram in Figure 12 reveals the cooling effect at the surface of the Shatt-al-Arab River at point 1. Looking at points 2 through 11 the Gulf is seen to be well stratified. Points 12 through 14 show the intrusion of less saline Arabian Sea water between the surface and 30m in the Gulf. Points 15 and 16 show that the Arabian Sea water in the northern part of the Gulf of Oman is contained in a layer from the surface to approximately 200m.

F. SUMMARY OF HYDROGRAPHIC INVESTIGATION

In summary, the water temperature throughout the Gulf is almost 10 °C warmer during summer than in winter. The salinity behaves differently, as it remains fairly constant throughout the year. The only exception occurs during the winter months when the discharge of fresh water from the Shatt-al-Arab River reduces the salinity in the northern portion of the Gulf.

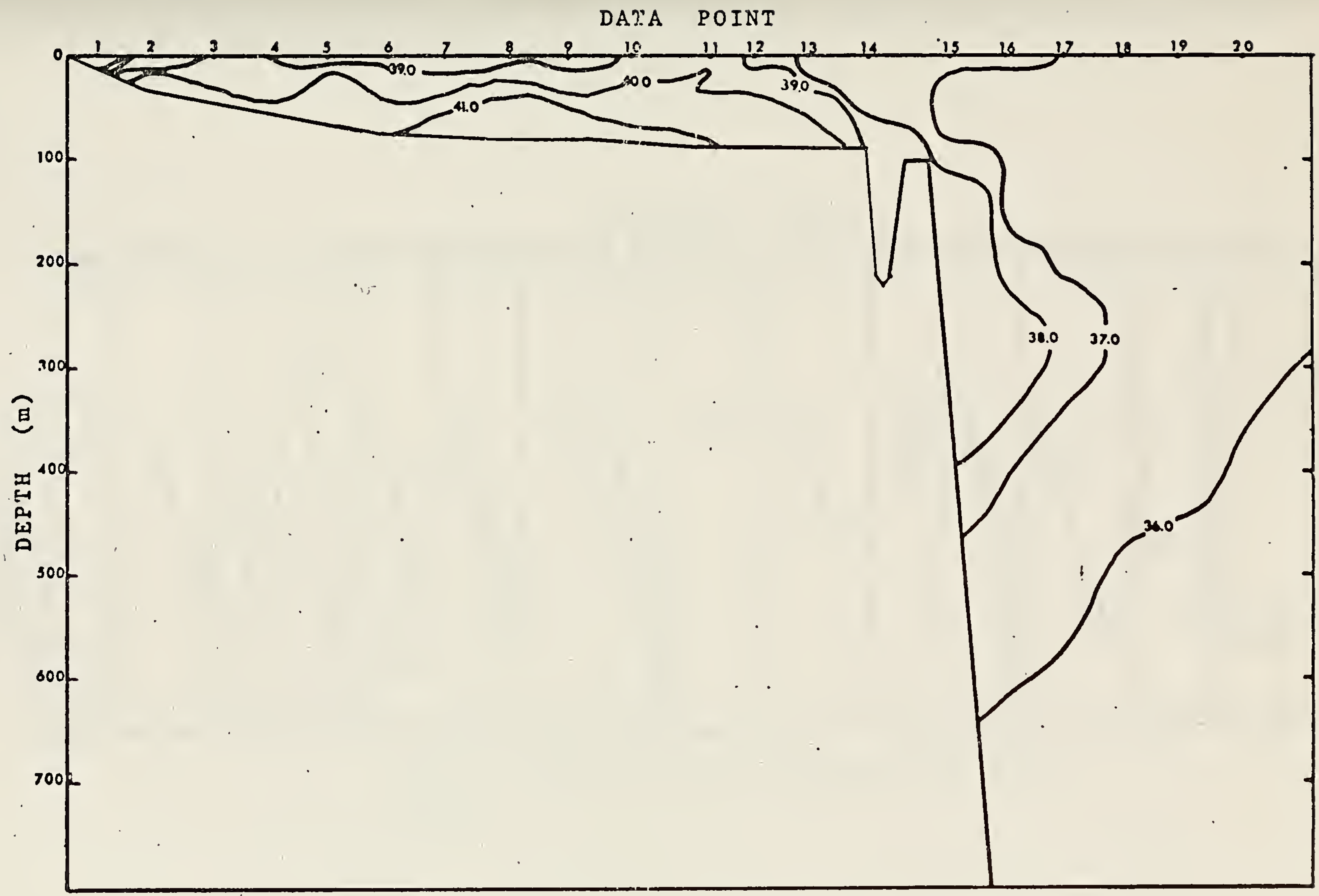

Figure 11. Vertical cross section of summer salinity (o/oo) along the transect. Locations 17-20 are based on mean values for the month of May.

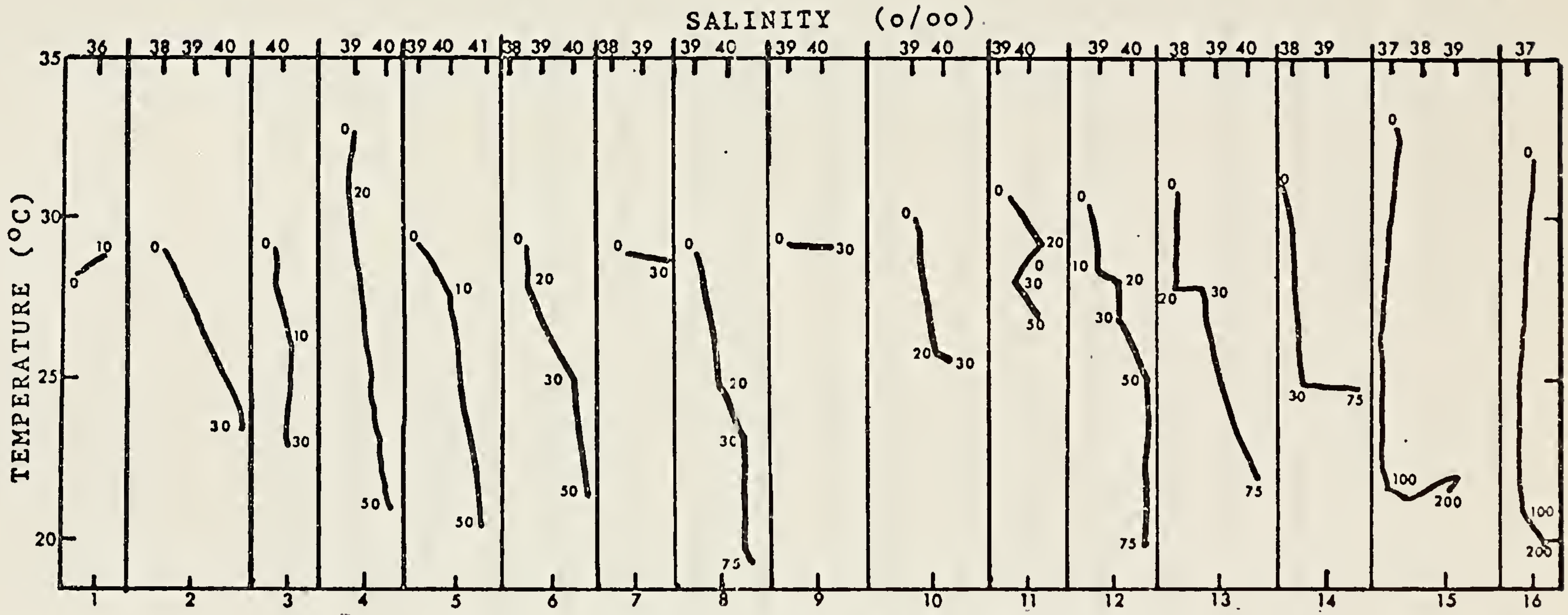

Figure 12. Nested summer T-S profiles along the transect

During both seasons there exists a region in the vicinity of the Straits of Hormuz, where the Persian Gulf water and Arabian Sea water meet causing an area of horizontal stratification. It is in this region where the most irregular temperature and salinity structures occur. The basic circulation of the Persian Gulf appears to remain the same year round; that is, there is an outflow of the Persian Gulf water at the bottom, through the Straits of Hormuz and an inflow of Arabian Sea water at the surface. In Figure 7 the basic circulation was shown as described by Sugden [1963]. The analysis of the mean values of temperature and salinity would suggest a slightly different circulation pattern. Figure 13 shows this alternative. As stated by Emery [1956], in the Strait of Hormuz there is an area of convergence where Persian Gulf water and Arabian Sea water come together. It appears from this analysis, based on mean temperature and salinity profiles, that Arabian Sea water does not penetrate into the Gulf very far beyond this point.

Without question the winds play a very important role in the circulation of the Gulf. Their actual influence has not been investigated; however, as surface winds are generally northwesterly throughout the year, the concept of a southerly surface flow in the Gulf is most logical.

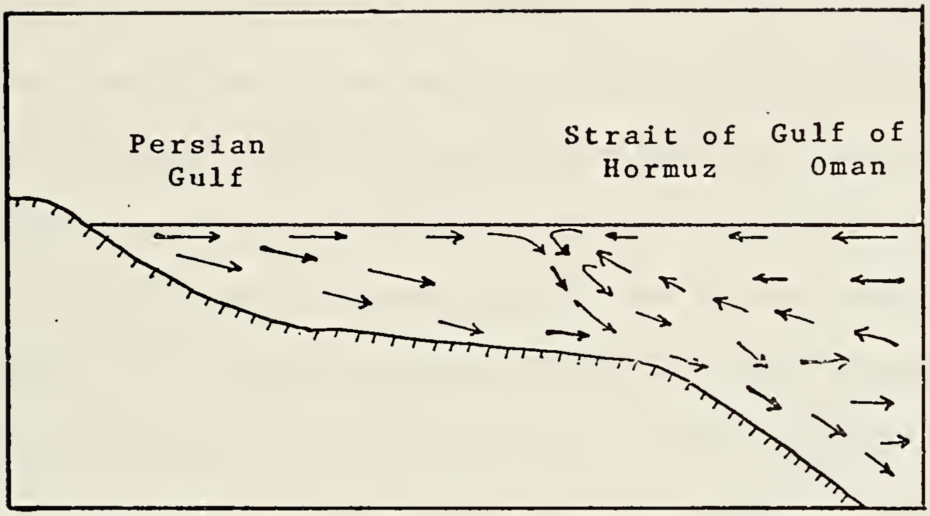

Figure 13. Modification of Sugden's 1963 diagramatic representation of water circulation in the Persian Gulf

IV. SOUND PROPAGATION INVESTIGATION

A. PROPAGATION LOSS ANALYSIS

The Fast Asymptotic Coherent Transmission model (FACT), a low frequency ray-acoustic model, was utilized to analyze acoustic propagation conditions in the Persian Gulf. This particular FORTRAN library program has been adapted to provide both graphical and numerical output of propagation loss versus range, as a function of a variety of input parameters shown in Table 1. Note that the bottom loss index, scale 1-5, is based on bottom composition, roughness, and slope. Basically, the Persian Gulf has a flat mud-sand bottom for which an intermediate loss index of 3 is assigned. In the Gulf of Oman a slope is present; however, the bottom is almost entirely sand, so the value of 3 is assumed to be valid.

Although salinity is high in the Persian Gulf (40 o/oo), it does not appear explicitly in the expression for absorption, but it is recognized that high values of salinity would increase the effect of the $MgSO_4$ relaxation process. Preliminary computations indicated that absorption coefficients would increase approximately 0.05% from the standard expression when considering a body of water with an average salinity of 40 o/oo. Therefore, this additional absorption factor was ignored.

After running the FACT program for the six frequencies at each point along the transect, it became obvious that an unwieldy number of

TABLE 1

FACT model input parameters

	PARAMETER	VALUE	HOW DETERMINED
1.	Layer Depth (ft)	Varied	Determined from temperature profile
2.	Bottom Loss index	3	Based on scale of 1 to 5 (1 low, 5 high)
3.	Sea State	February 2 July 3	Based on scale of 2, 3, 4. Winds light in winter; shamal winds present in summer
4.	Frequencies (Hz)	300, 500, 1000, 3500 5000, 8000	Arbitrary. These frequencies cover most passive and active detection systems
5.	Source/ Receiver Depth Combinations (ft)	60/60 300/300 60/300	Arbitrary These combinations provide for source/receiver in layer, below layer, and mixed

graphical representations would be required to describe the results. Thus, methods of reducing the amount of data without loss of continuity were investigated. Utilizing the nested T-S plots and FACT generated propagation loss curves, it was found that large areas of the Gulf along the transect were acoustically similar. Hence the transects were portioned into areas according to their hydrographic and acoustic similarities. These acoustic areas are shown in Figures 14 and 15 with the 10 fathom (18m) bottom contour defining the approximate limits for a submerged submarine. A further reduction of data was made in that the 500Hz and 5000Hz propagation loss curves could be eliminated from the investigation, because they closely matched those of 300Hz and 3500Hz, respectively.

The resulting propagation loss curves for summer and winter conditions are shown in Appendix B.

In order to use the propagation loss profiles to determine the seasonal and geographic variability of detection ranges, it was necessary to generate Figures of Merit (FOM) for passive and active detection systems. It was assumed that passive detection would be made by an air dropped sonobuoy and active detection would be made by a hull mounted sonar. For the passive analysis FOM's were computed for 300Hz and 1000Hz signals, for both a snorkeling diesel and a nuclear submarine. The FOM's for the hull mounted sonars were based on

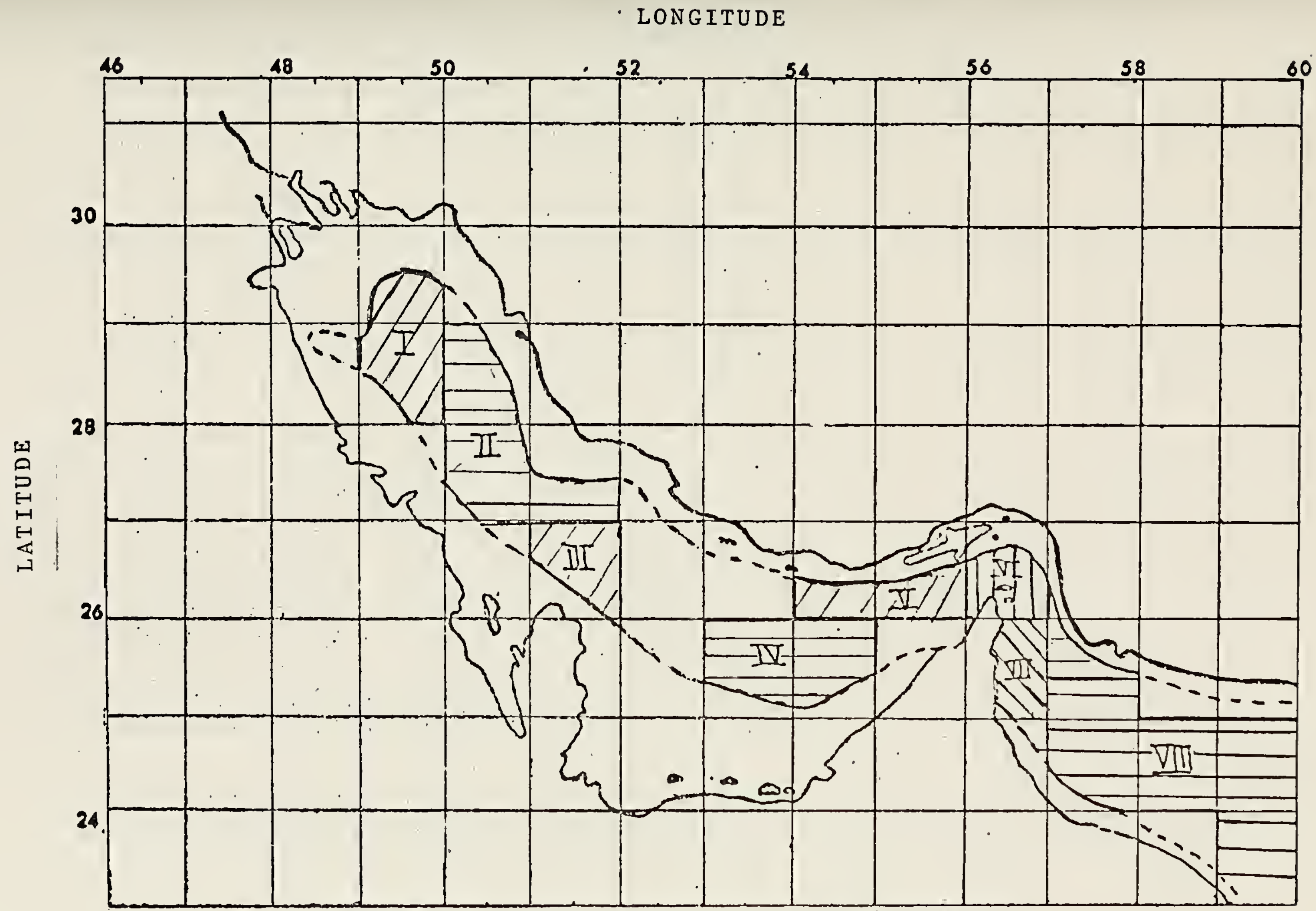

Figure 14. Winter areas of acoustic similarity.
Each area is assumed to be acoustically homogeneous.

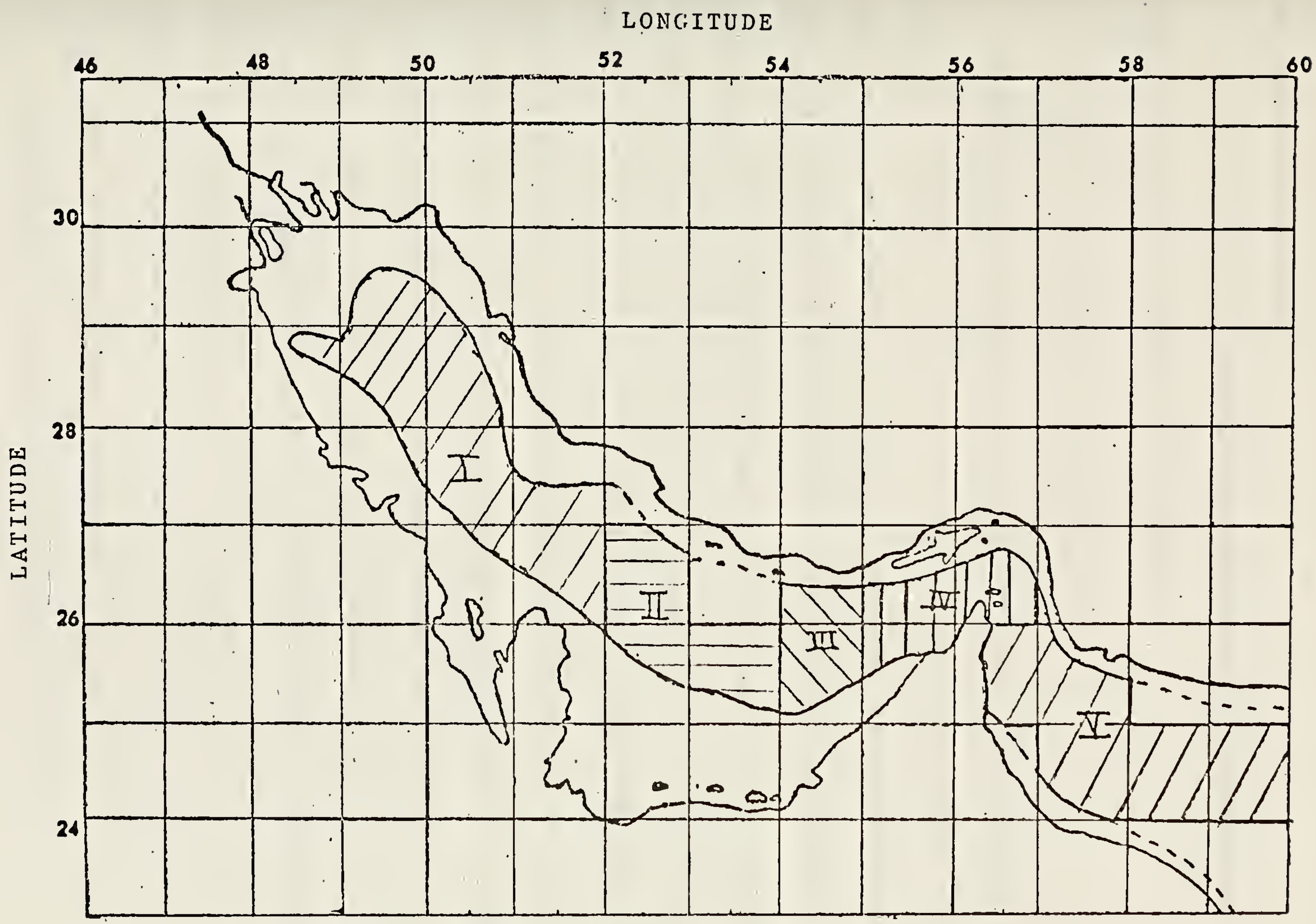

Figure 15. Summer areas of acoustic similarity.
Each area is assumed to be acoustically homogeneous.

transmission frequencies of 3500Hz and 8000Hz. The resulting FOM's are shown in Table 2. The sonar equations and associated calculations are located in Appendix C.

Tables 3 and 4 show the passive and active detection ranges for the winter and summer seasons, respectively.

B. SUMMARY OF SOUND PROPAGATION

Several important points can be gleaned from the propagation loss profiles in general. The most significant point is to question what physical processes or mechanisms permit detection ranges of 30 nm, seen in Tables 3 and 4, to exist in a "hot bath tub" like the Persian Gulf. The propagation loss profiles in Appendix B show that there is little loss of acoustic energy in Areas II, IV, V, VI, VII in winter. The loss that does occur falls in the range between cylindrical and spherical spreading favoring the former. In these areas the positive sound speed gradients present cause the Gulf to act as a waveguide with minimal surface scattering and bottom loss. The propagation loss in areas I, III, VIII in winter and in areas I, II, III, IV, V in summer is greater because there is no capability for channeling of sound energy. Losses greatly exceed spherical spreading ($1/r^2$) often approaching a $1/r^3$ loss rate. Again, this is a function of the sound speed profile, which in these areas has a negative gradient (Appendix D). Comparing the two situations it is apparent that the shape of the sound speed profile, and not the high

TABLE 2

Figures of Merit
for summer and winter for the passive and active cases

Passive FOM's (db re 1 μ bar) for summer and winter

Nuclear Submarine

FREQ	FOM
300 Hz	82 db
1000 Hz	92 db

Snorkeling Diesel Submarine

FREQ	FOM
300Hz	85 db
1000Hz	95 db

Active FOM's (db re 1 u bar) for summer and winter

FREQ	FOM
3500Hz	195 db
8000Hz	180db

TABLE 3

Passive detection ranges (nm) for summer and winter

WINTER

Freq	300 Hz		1000 Hz	
Area	Diesel	Nuc	Diesel	Nuc
I	6	5	7	5
II	30	30	30	30
III	8	5	11	8
IV	30	30	30	30
V	30	30	30	30
VI	30	20	30	30
VII_{SS}	23	20	30	30
VII_{DD}	30	30	30	30
VII_{SD}	18	4	30	30
$VIII_{SS}$	13	6	13	14
$VIII_{DD}$	11	7	14	13
$VIII_{SD}$	11	7	16	13

SUMMER

	300 Hz		1000 Hz	
Area	Diesel	Nuc	Diesel	Nuc
I	3	3	5	4
II	6	3	18	17
III	4	3	6	4
IV	3	3	5	4
V_{SS}	7	7	15	8
V_{DD}	30	30	30	30
V_{SD}	7	6	11	9

NOTE: Roman numeral subscripts indicate depth of source and receiver, i.e., SS means both are at 60 ft. Roman numeral without subscripts are SS.

TABLE 4

Active detection ranges (nm) for summer and winter

WINTER

Freq Area	3500 Hz	8000 Hz
I	7	4
II	30	13
III	8	5
IV	30	12
V	30	15
VI	29	10
VII_{SS}	13	7
VII_{DD}	29	14
VII_{SD}	28	7
$VIII_{SS}$	16	10
$VIII_{DD}$	13	10
$VIII_{SD}$	14	7

SUMMER

Freq Area	3500 Hz	8000 Hz
I	4	4
II	30	12
III	4	4
IV	4	4
V_{SS}	8	7
V_{DD}	30	13
V_{SD}	9	6

NOTE: Source and receiver setting of deep-deep is meaningless for a hull mounted sonar.

water temperature, appears to be the controlling factor of sound propagation in the Persian Gulf.

Another feature of the propagation loss profiles is its "spikey" appearance. This is a result of surface-image interference, and the spikes represent areas of higher energy in which direct path or refracted rays are reinforced by surface reflected rays. The position of the spikes on the propagation loss profile does not guarantee their presence in a particular location. This is because the FACT model calculations are based on a flat bottom, thus, any bottom irregularities or bottom slope would cause the spacing between spikes and their relative intensities to vary from that predicted.

As the sound propagation investigation is based on a mean analysis, the effects of perturbations caused by a shamal wind are not considered. However, it can be assumed that a shamal wind would reduce detection ranges by increasing surface scattering and surface reverberation.

1. Passive Case

Generally, the longest detection ranges can be expected to occur during the winter season. This was anticipated because of the greater evaporation rate in the winter, causing convective mixing which breaks down the stratification of summer and creates positive or isothermal sound speed gradients. On the other hand, shorter ranges are observed during the summer season due to the negative sound speed gradients resulting from stratification of the Gulf waters. Appendix D contains the sound speed profiles for both seasons.

Geographically, there is little pattern to the passive detection ranges. An exception occurs during the winter months when throughout the entire Gulf, excluding the northern end which is affected by the Shatt-al-Arab River, approximately the same detection ranges exist for both frequencies investigated.

2. Active Case

With regard to active detection ranges, the seasonal trend is similar to that of the passive case, note Table 4. Also, as expected, the detection ranges are less for the 8000Hz signal due to the increased attenuation associated with higher frequencies. There are no trends in the geographical locations of the sampled areas.

The extremely long active detection ranges found in Table 4 are questionable. As mentioned previously, the volume reverberation in the Persian Gulf is essentially an unknown quantity. Without knowledge of this factor the Figures of Merit may be excessive and thus detection ranges overly optimistic.

V. CONCLUSIONS

The Persian Gulf has received little attention in oceanographic literature, and what scant information is available is derived from geophysical and oil exploration cruises where ocean acoustics has played a minor role. Although, these surveys are extremely valuable tools to the descriptive oceanographer, the approach to these surveys has been neither coordinated nor systematic. Thus, a description of the seasonal and geographic variation of oceanographic parameters is difficult in certain areas of the Gulf.

The Gulf can be characterized as being well mixed during the winter due to convective mixing caused by a high evaporation rate. In the summer the Gulf is stratified and what mixing occurs is caused by wind. The most interesting region in the Gulf area is in the vicinity of the Strait of Hormuz where Persian Gulf water encounters Arabian Sea water.

Acoustically the Gulf has long detection ranges during the winter resulting from isovelocity and positive sound speed profiles. During the summer the sound speed profiles have negative gradients, thus detection ranges are reduced. Although in comparison with the major world oceans, the Persian Gulf is unusually warm and saline, the controlling factor in sound propagation appears to be the shape of the sound speed profile.

The Persian Gulf has become strategically important to major powers of the world. Therefore, it follows that the oceanographic characteristics of the Gulf, and their influence on military operations, will be studied in depth. A Naval Underwater Systems Center cruise in 1975 would be just a beginning.

APPENDIX A

NODC TAPE DATA TRANSFER PROGRAM

```
FORTRAN IV G LEVEL  20                    MAIN                DATE = 74029

           CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
           C              NODC TAPE TRANSFER PROGRAM           C
           C >>>>>>>>>>>>XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX C
           C       THIS PROGRAM WILL READ A 9-TRACK NODC       C
           C       TAPE AND TRANSFER THE DATA TO A 9-TRACK     C
           C       NPS TAPE. BY PROPER UTILIZATION OF THE      C
           C       "DATA ISIX..." CARD, SPECIFIC DATA ONLY     C
           C       MAY BE TRANSFERRED.                         C
           CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
0001               DIMENSION IVAL(21)
0002               DATA NREAD,NPRINT,NPUNCH/5,6,7/
           CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
           C       NODC TAPE INCLUDES THREE SETS OF DATA.      C
           C       SETS ARE DELINEATED BY THE LAST DIGIT ON    C
           C       EACH CARD. I.E.,A 6 IN COLUMN 80 SIGNI-     C
           C       FIES STANDARD DEPTH DATA. BY DECLARING      C
           C       ISIX EQUAL TO 6, ALL STANDARD DEPTH         C
           C       DATA WILL BE TRANSFERRED ONLY.              C
           CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
0003               DATA ISIX/'6   '/
0004               ICHK=0
           CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
           C       DO LOOP LOOKS AT CARD ON NODC TAPE AND      C
           C       INVESTIGATES FOR THE NUMBER IN COLUMN       C
           C       80. IF IT IS EQUAL TO ISIX, THE CARD IS     C
           C       THEN PRINTED AND/OR PUNCHED DEPENDENT       C
           C       ON THE WRITE STATEMENT BEING UTILIZED.      C
           CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
0005               DO 100 IJ=1,100000
0006               READ (2,10,ERR=98,END=99)(IVAL(I),I=1,21)
0007            10 FORMAT (19A4,A3,A1)
0008               IF (IVAL(21).NE.ISIX) GO TO 100
0009               WRITE (7,10)(IVAL(I),I=1,21)
0010               WRITE (6,11) (IVAL(I),I=1,21)
0011            11 FORMAT (1X,19A4,A3,A1)
0012               ICHK=ICHK+1
0013               GO TO 100
0014            98 WRITE (6,20) IJ
0015            20 FORMAT (1X,I5,5X,'IS THE NUMBER OF THE RECORD WITH THE ERROR')
0016           110 IF (IJ.GT.45596) GO TO 200
0017           100 CONTINUE
0018            99 WRITE (6,88) IJ
0019            88 FORMAT (1X,'END OF FILE HAVING READ',I7,'FILES')
0020           200 CONTINUE
           CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
           C       ICHK IS THE TOTAL NUMBER OF DATA CARDS      C
           C       TRANSFERRED TO THE NPS TAPE.                C
           CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
0021               WRITE (6,103) ICHK
0022           103 FORMAT (5X,I5)
0023               STOP
0024               END
```

APPENDIX B

Propagation loss profiles for winter and summer. Each profile is for a particular area of acoustic similarity. (Refer to Figs. 19 and 20).

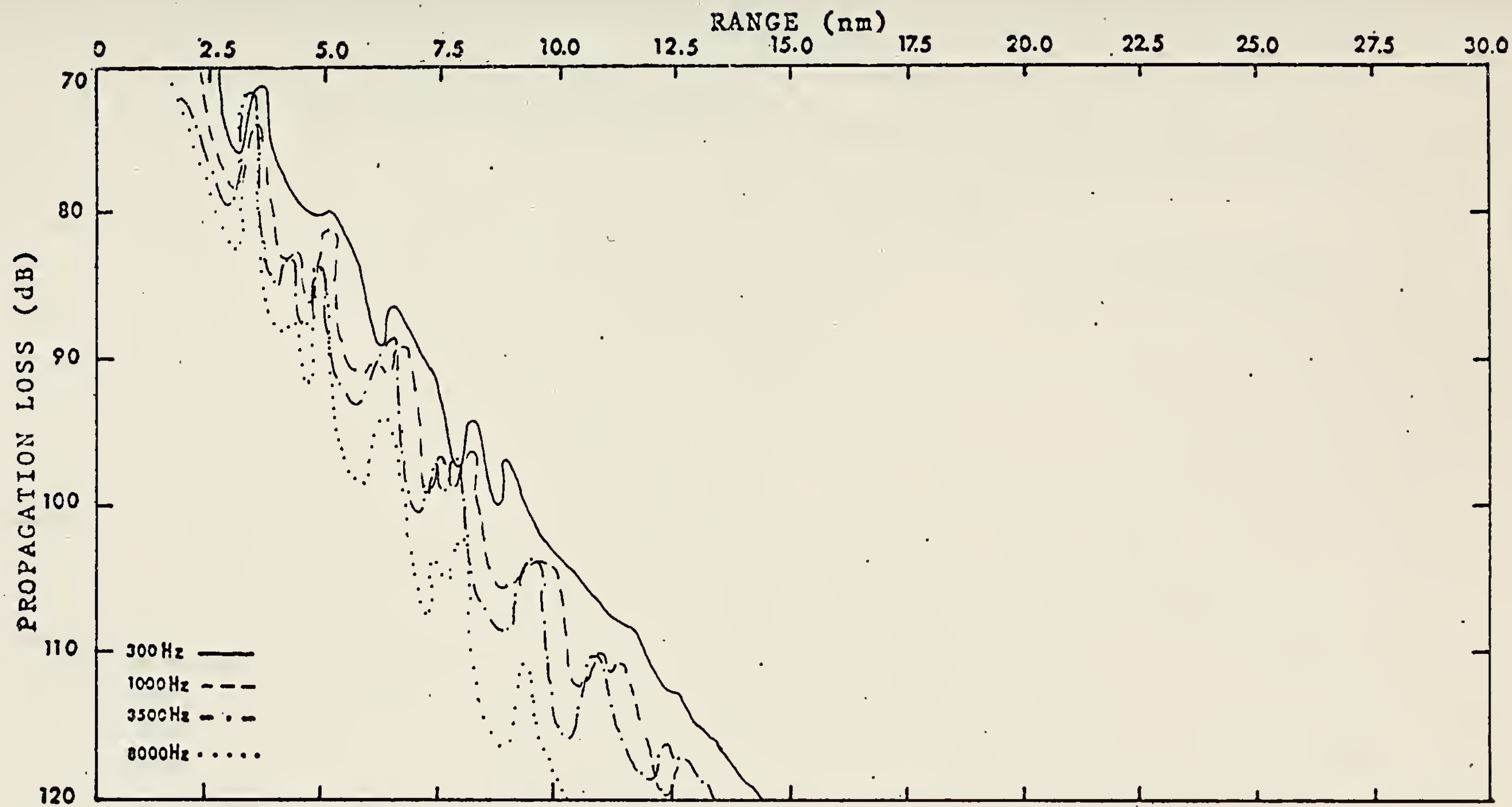

Figure B-1 . Propagation loss profile for area I during winter. Source at 60 ft, receiver at 60 ft.

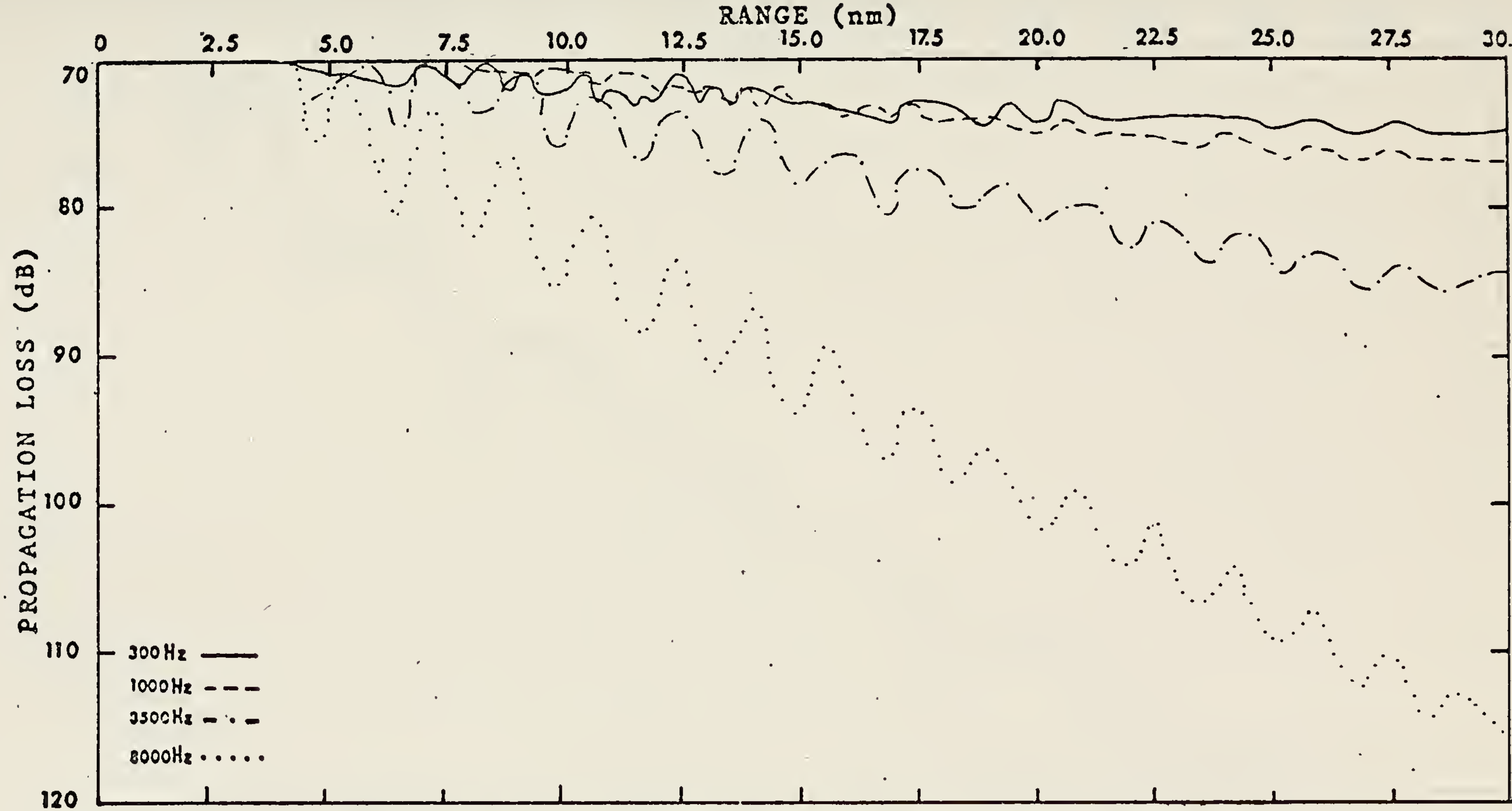

Figure B-2 . Propagation loss profile for area II during winter. Source at 60 ft, receiver at 60 ft.

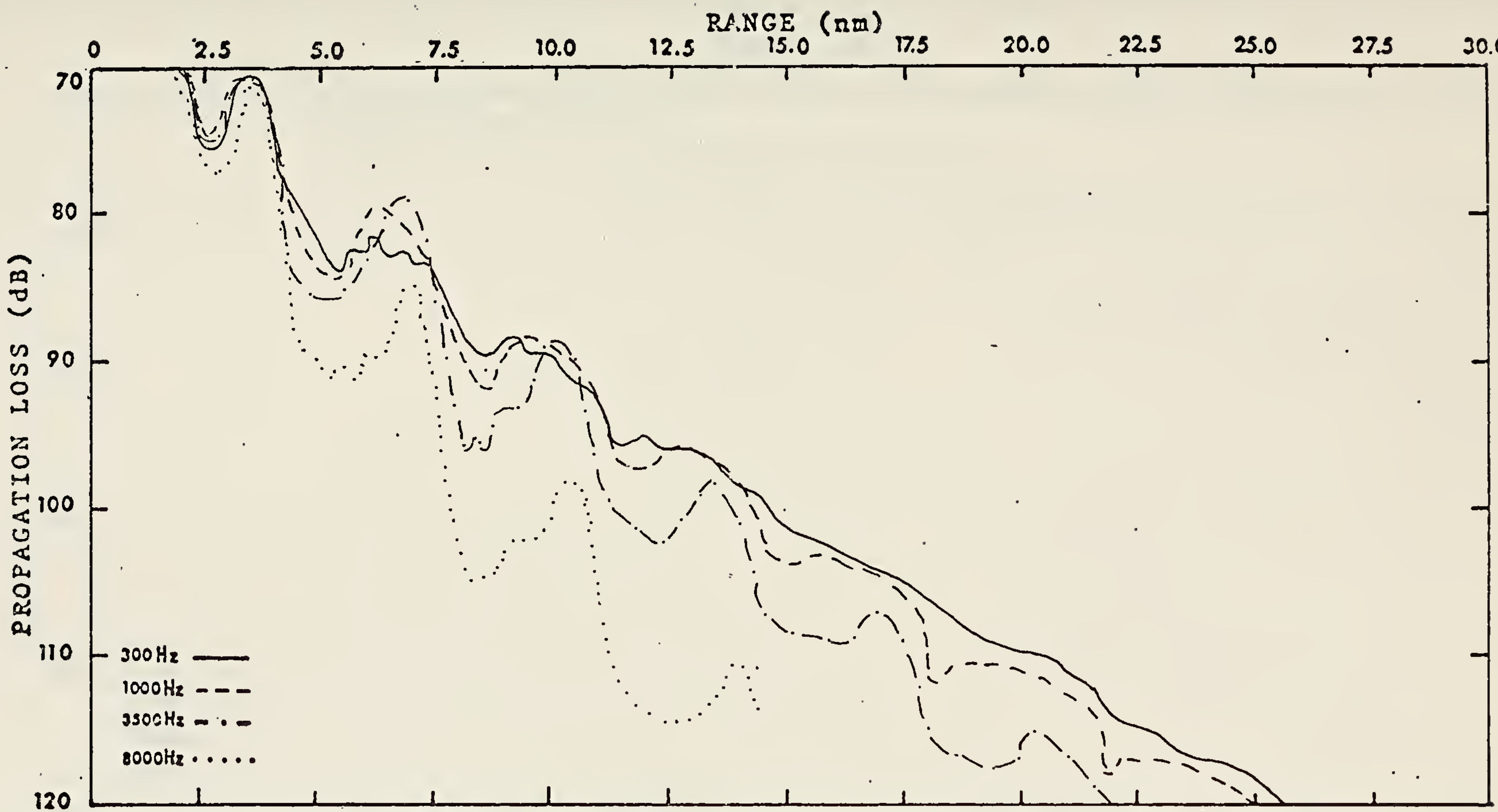

Figure B-3 . Propagation loss profile for area III during winter. Source at 60 ft, receiver at 60 ft.

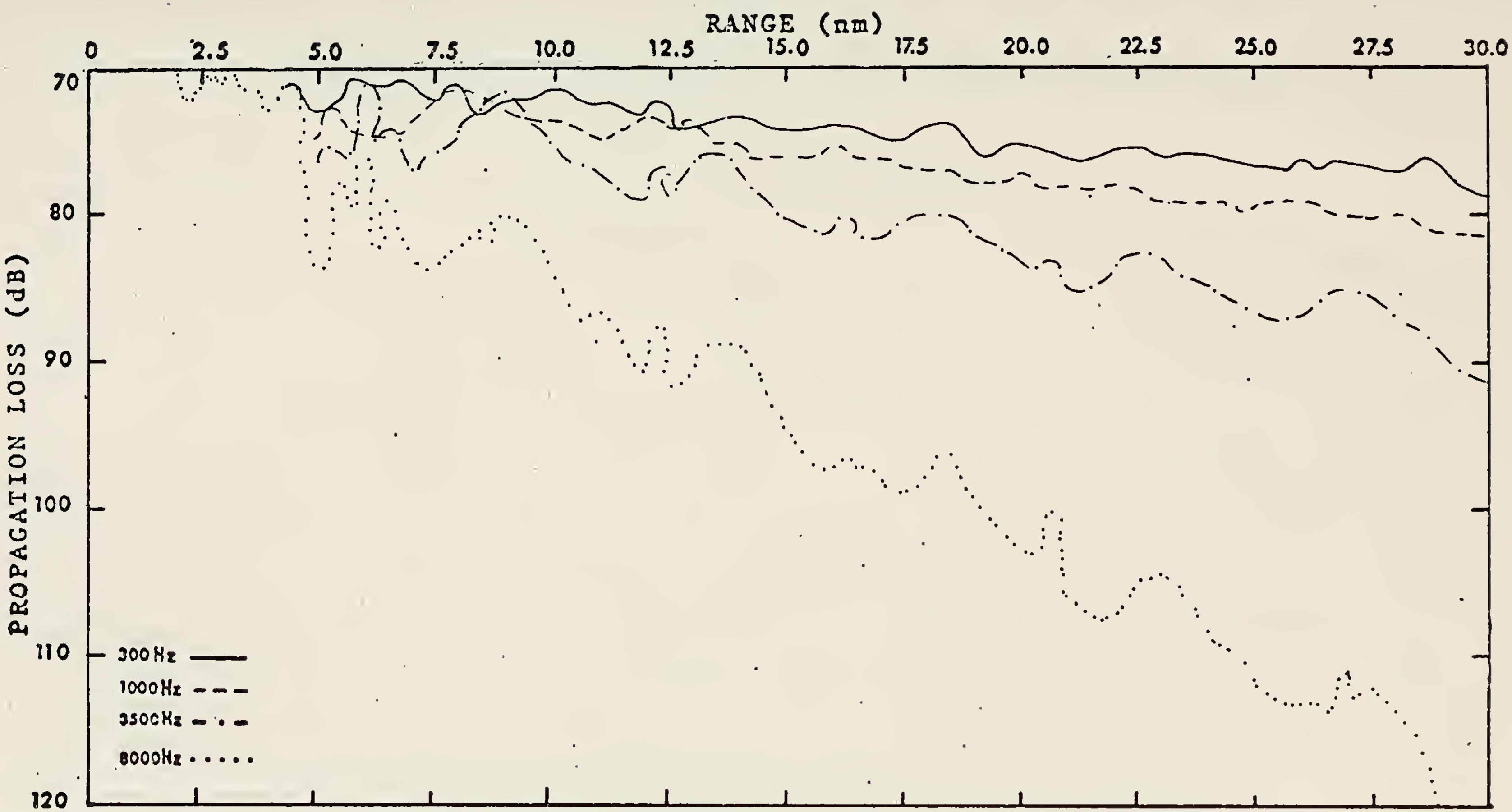

Figure B-4 . Propagation loss profile for area IV during winter. Source at 60 ft, receiver at 60 ft.

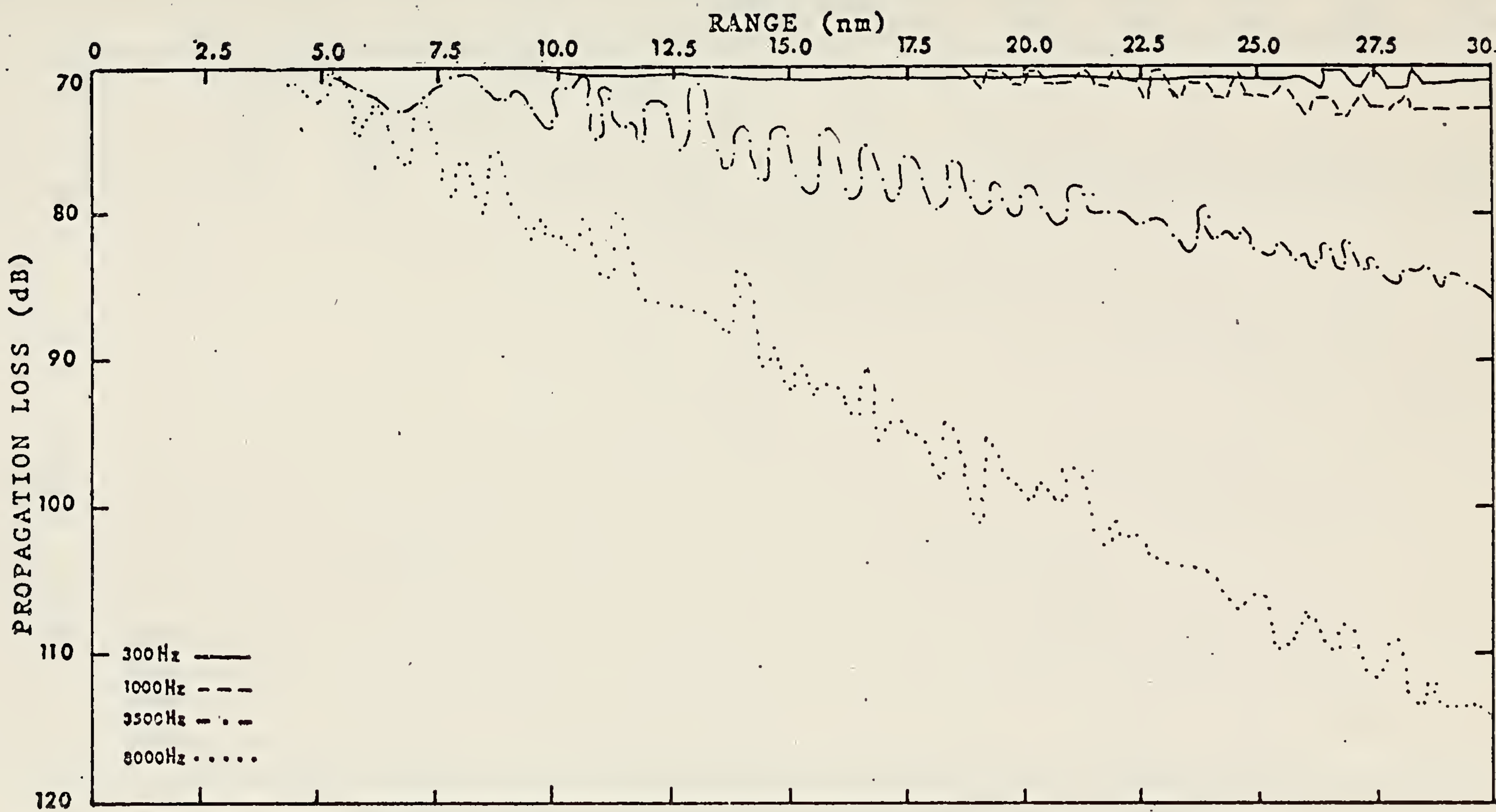

Figure B-5 . Propagation loss profile for area v during winter. Source at 60 ft, receiver at 60 ft.

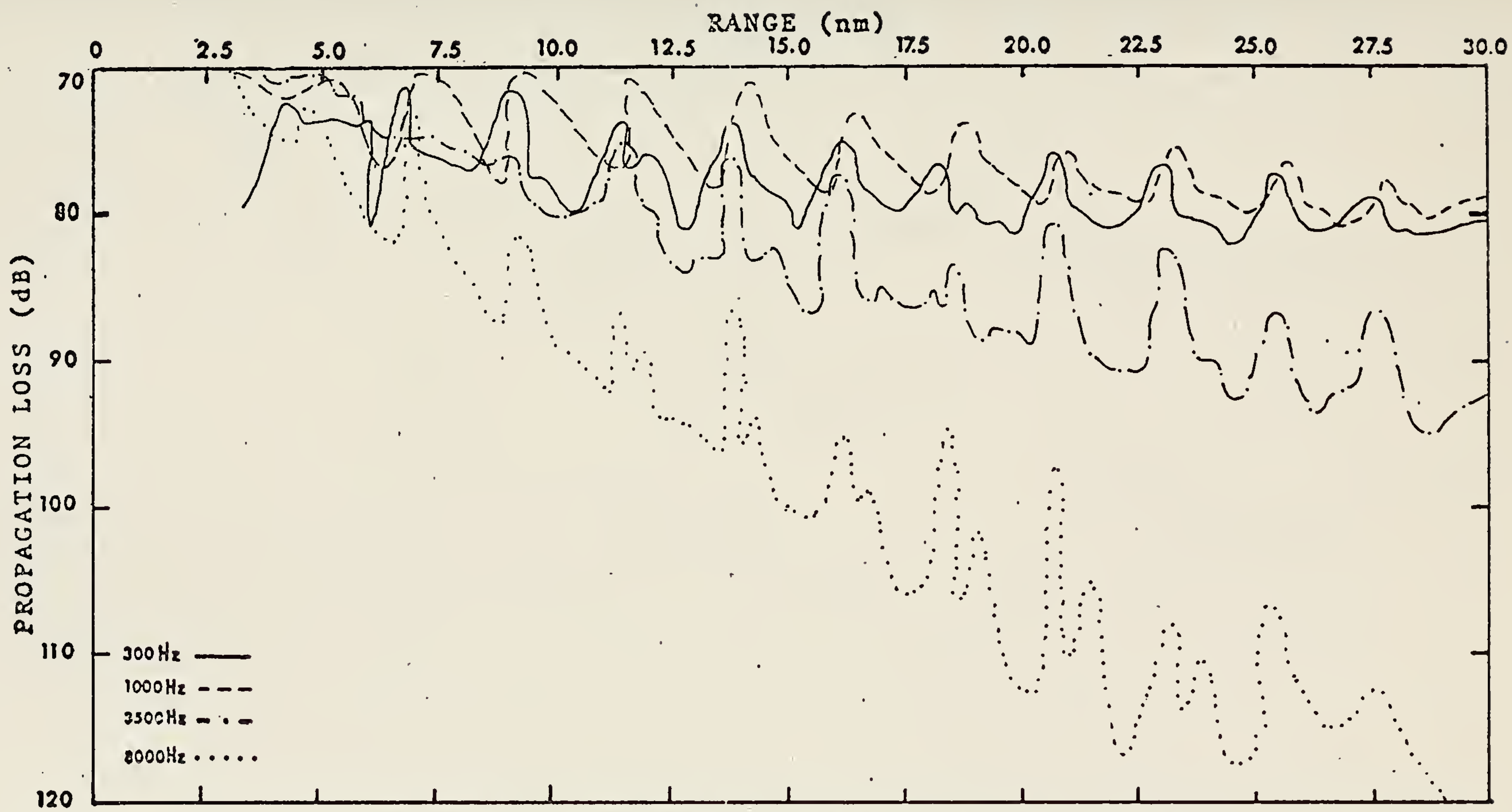

Figure B-6 . Propagation loss profile for area VI during winter. Source at 60 ft, receiver at 60 ft.

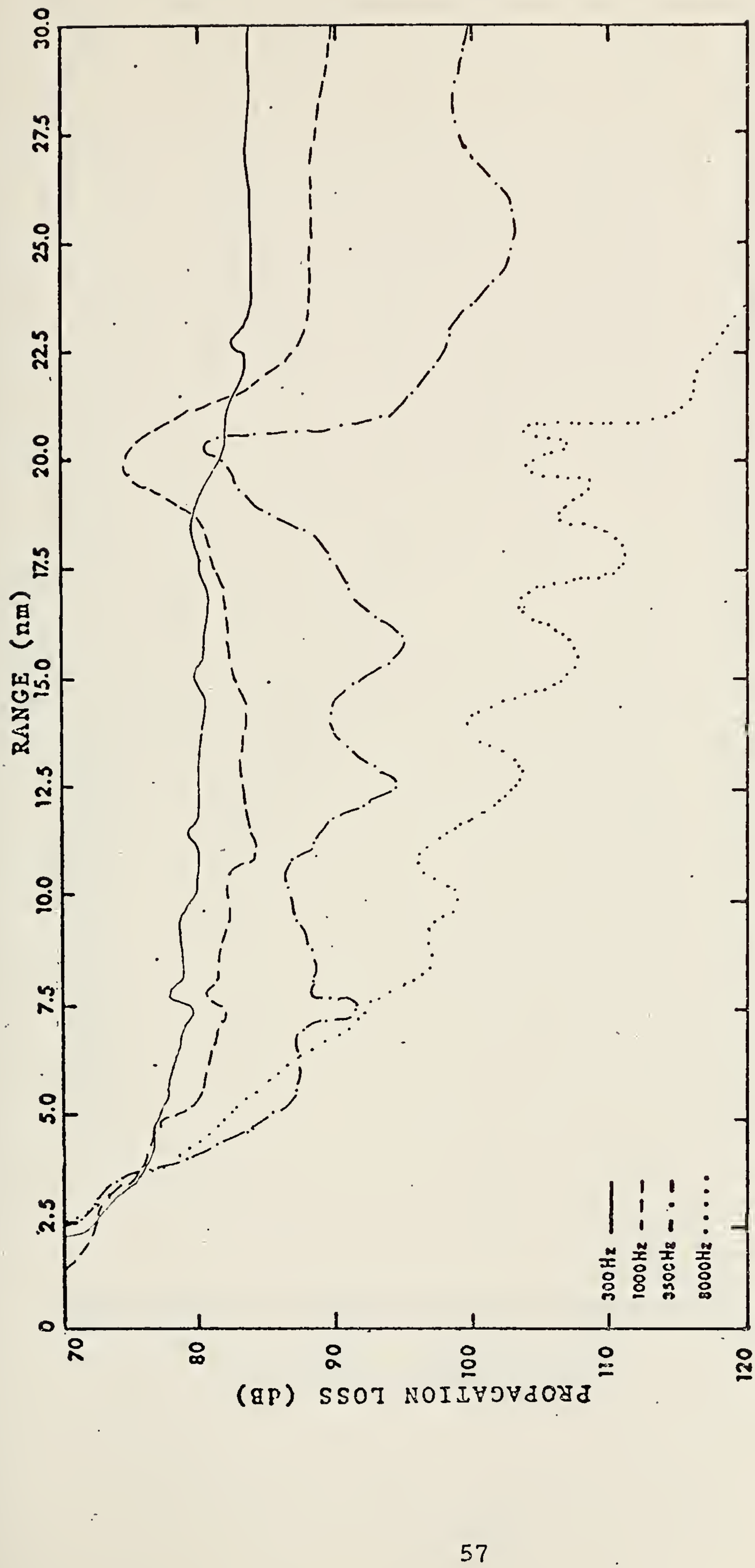

Figure B-7 . Propagation loss profile for area VII during winter. Source at 60 ft, receiver at 60 ft.

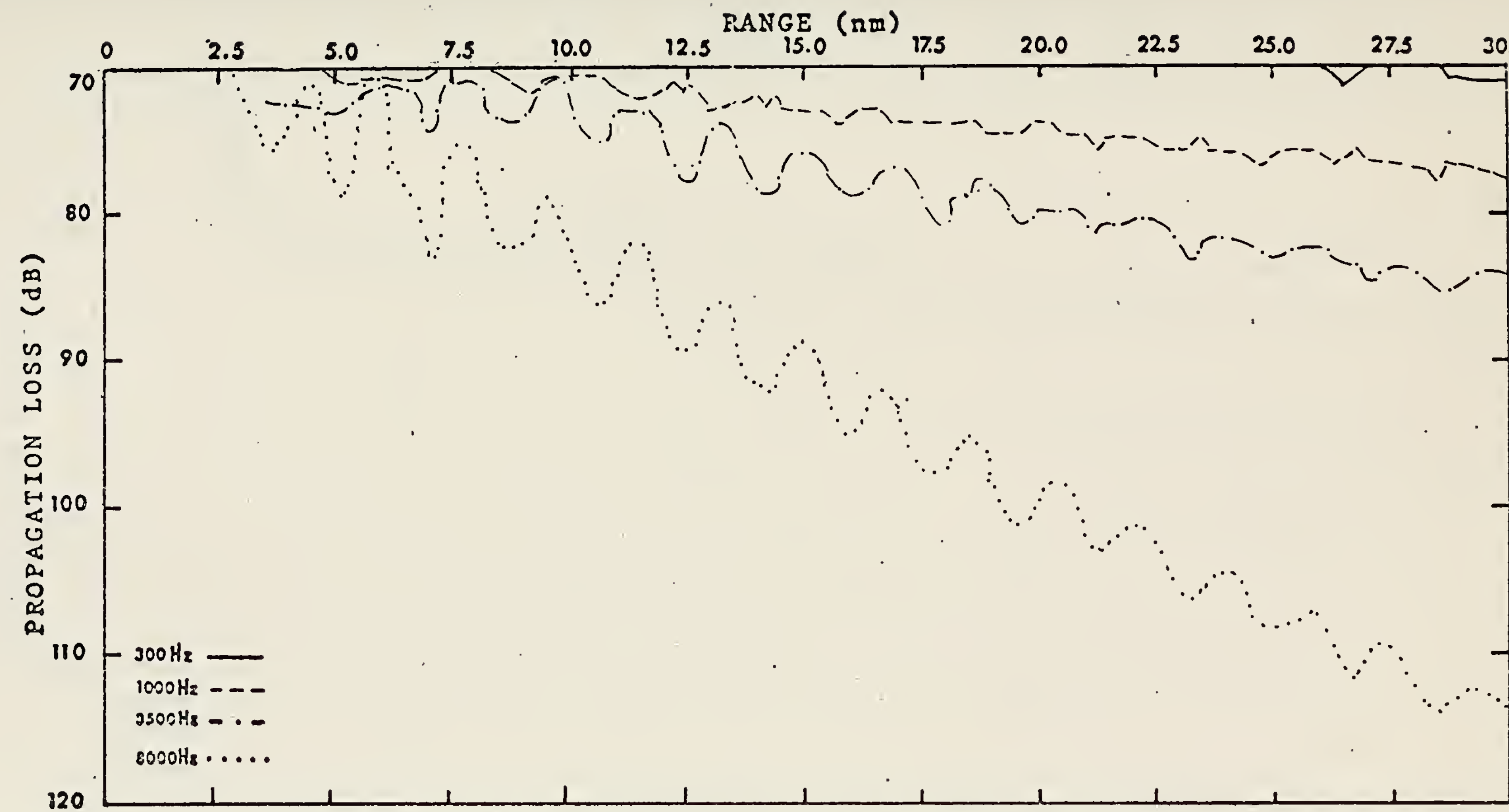

Figure B-8 . Propagation loss profile for area VII during winter. Source at 300 ft, receiver at 300 ft.

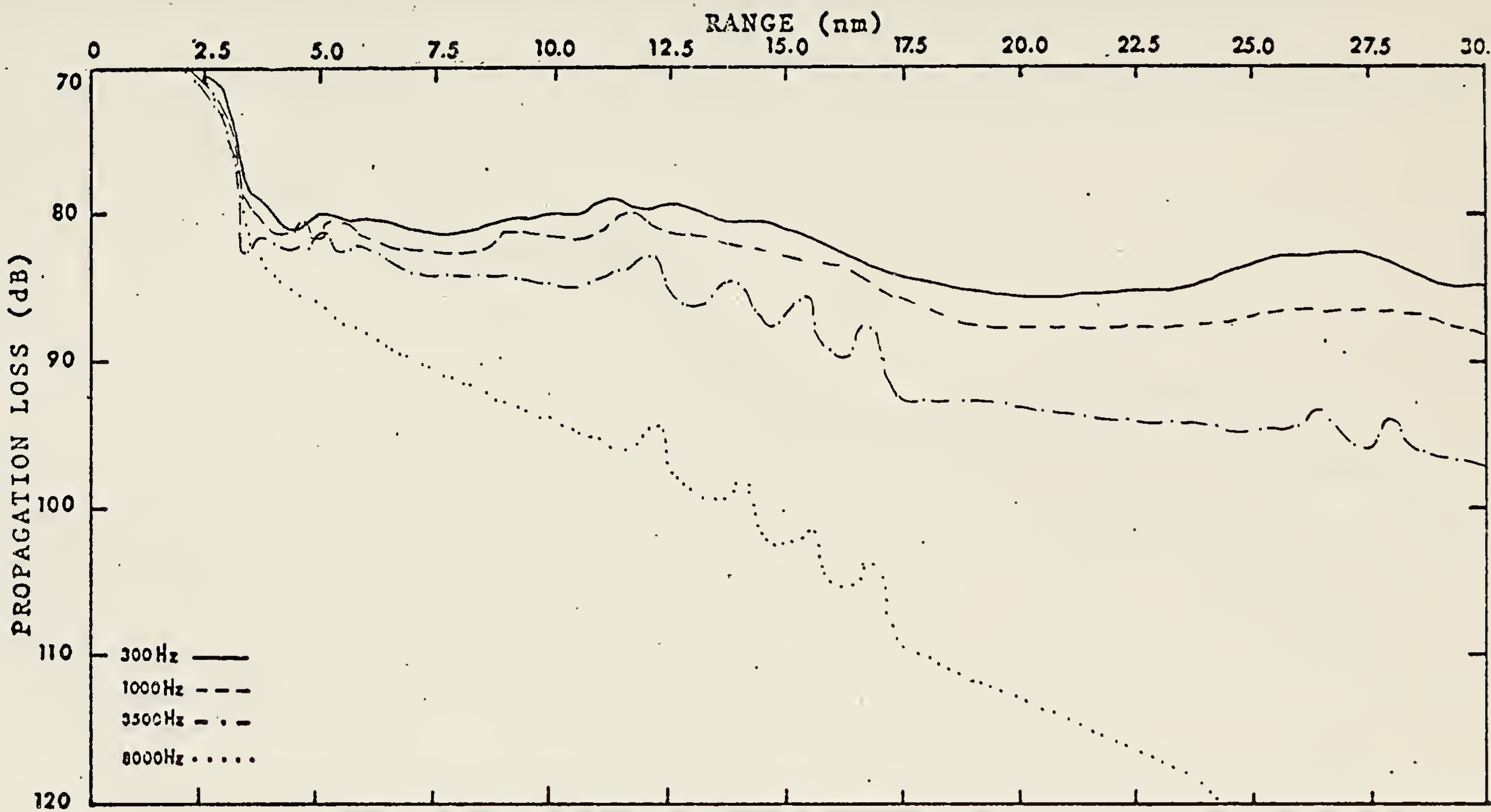

Figure B-9 . Propagation loss profile for area VII during winter. Source at 60 ft, receiver at 300 ft.

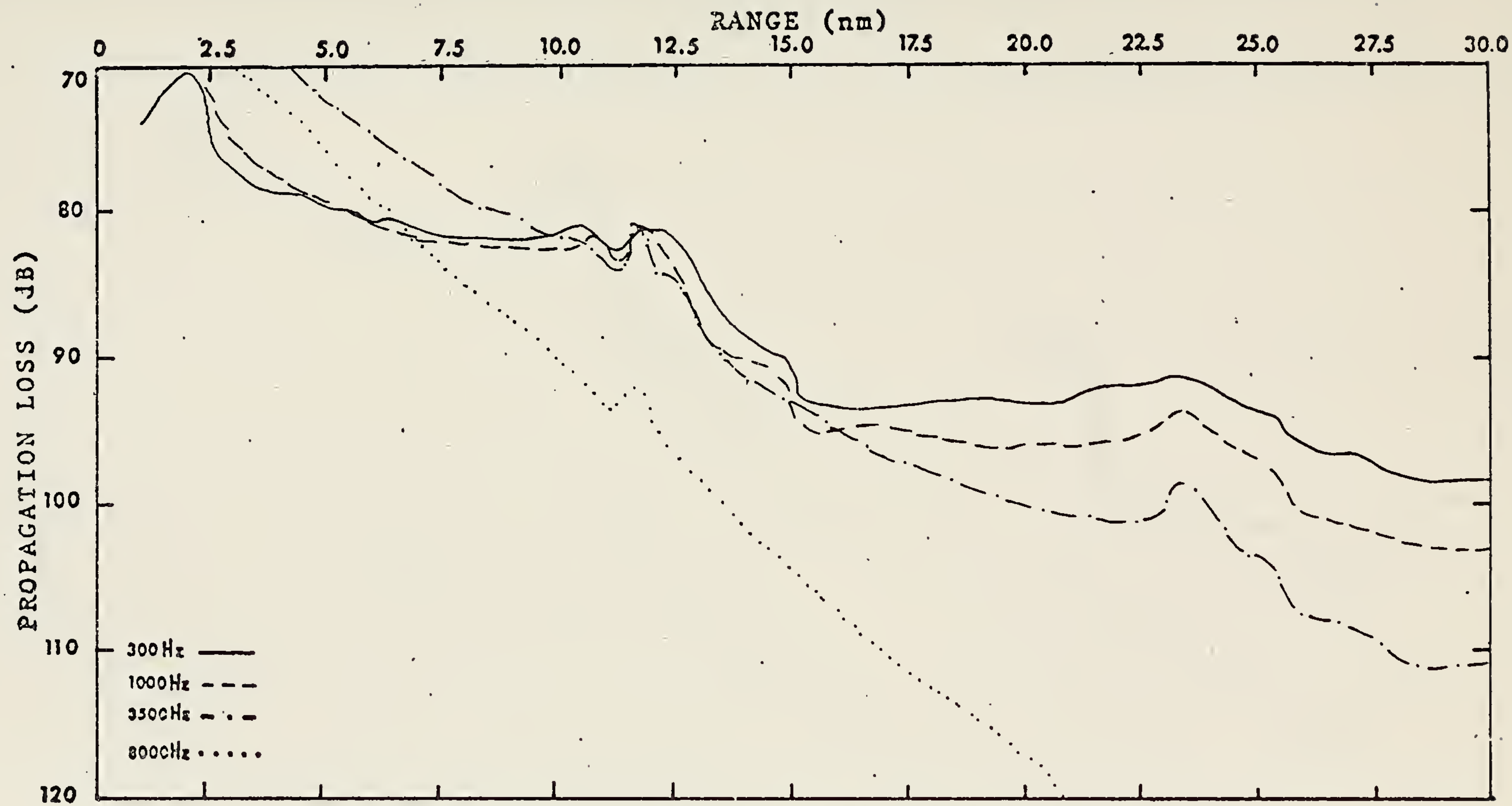

Figure B-10. Propagation loss profile for area VIII during winter. Source at 60 ft, receiver at 60 ft.

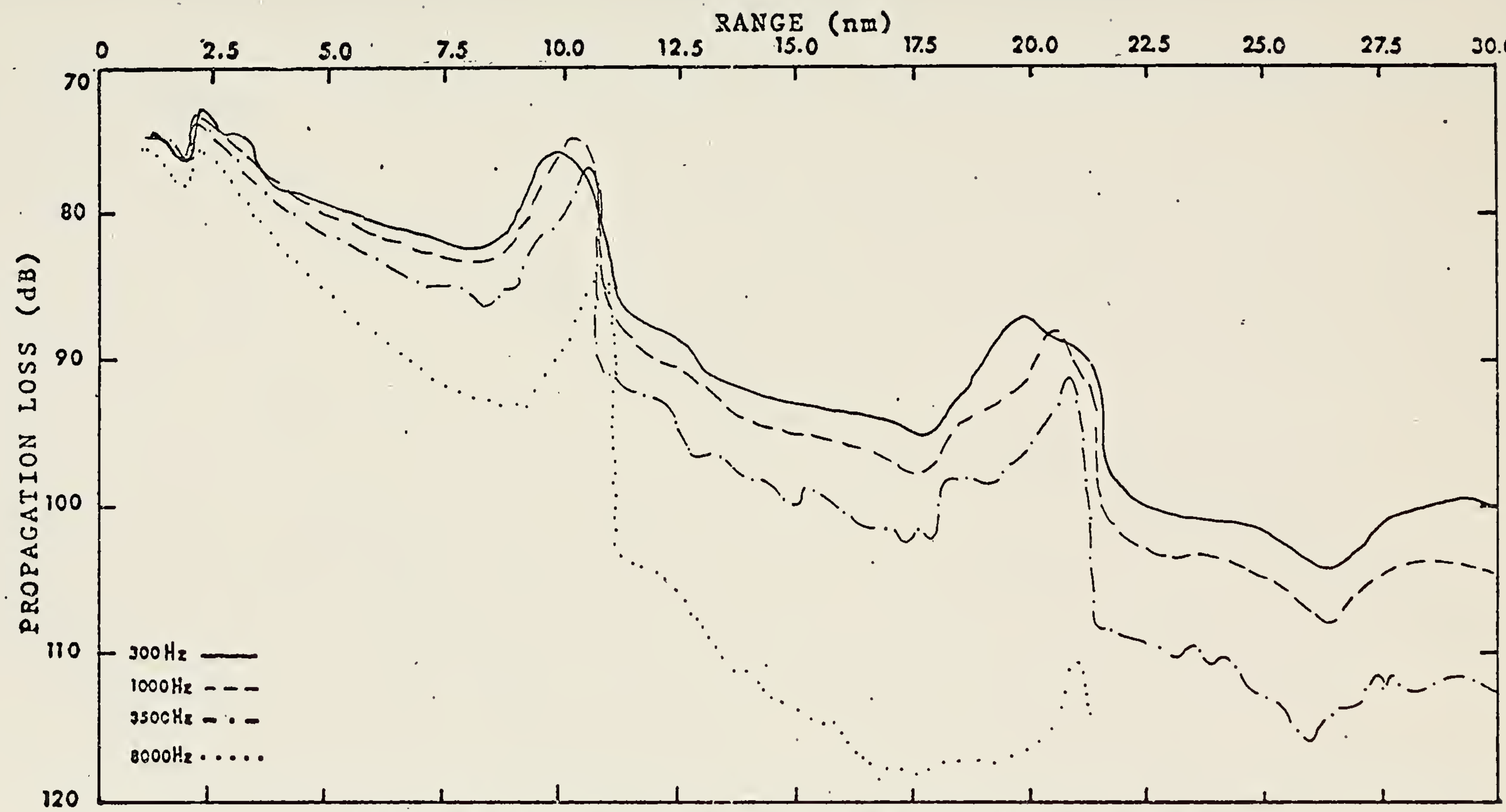

Figure B-11 . Propagation loss profile for area VIII during winter. Source at 300 ft, receiver at 300 ft.

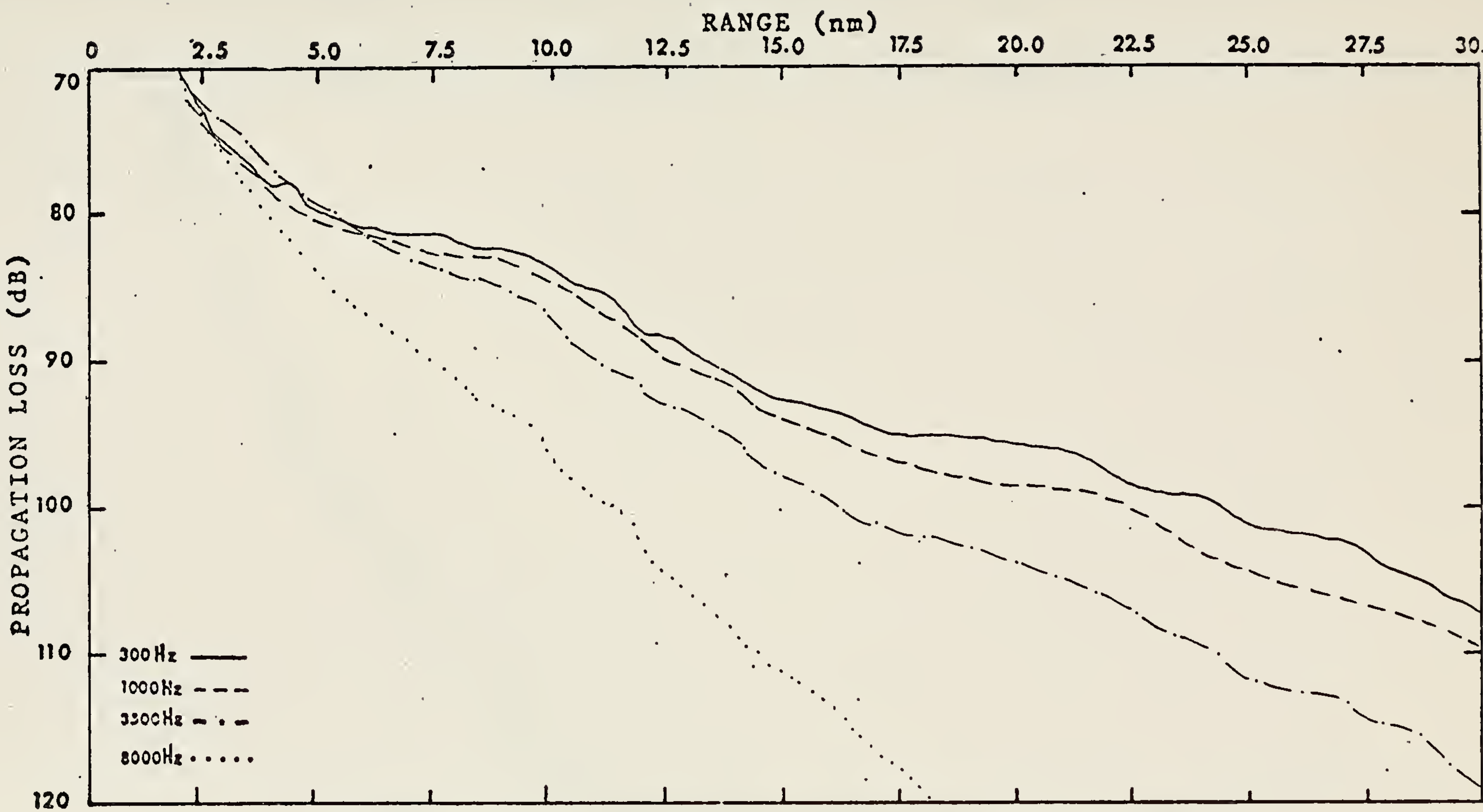

Figure B-12. Propagation loss profile for area VIII during winter. Source at 60 ft, receiver at 300 ft.

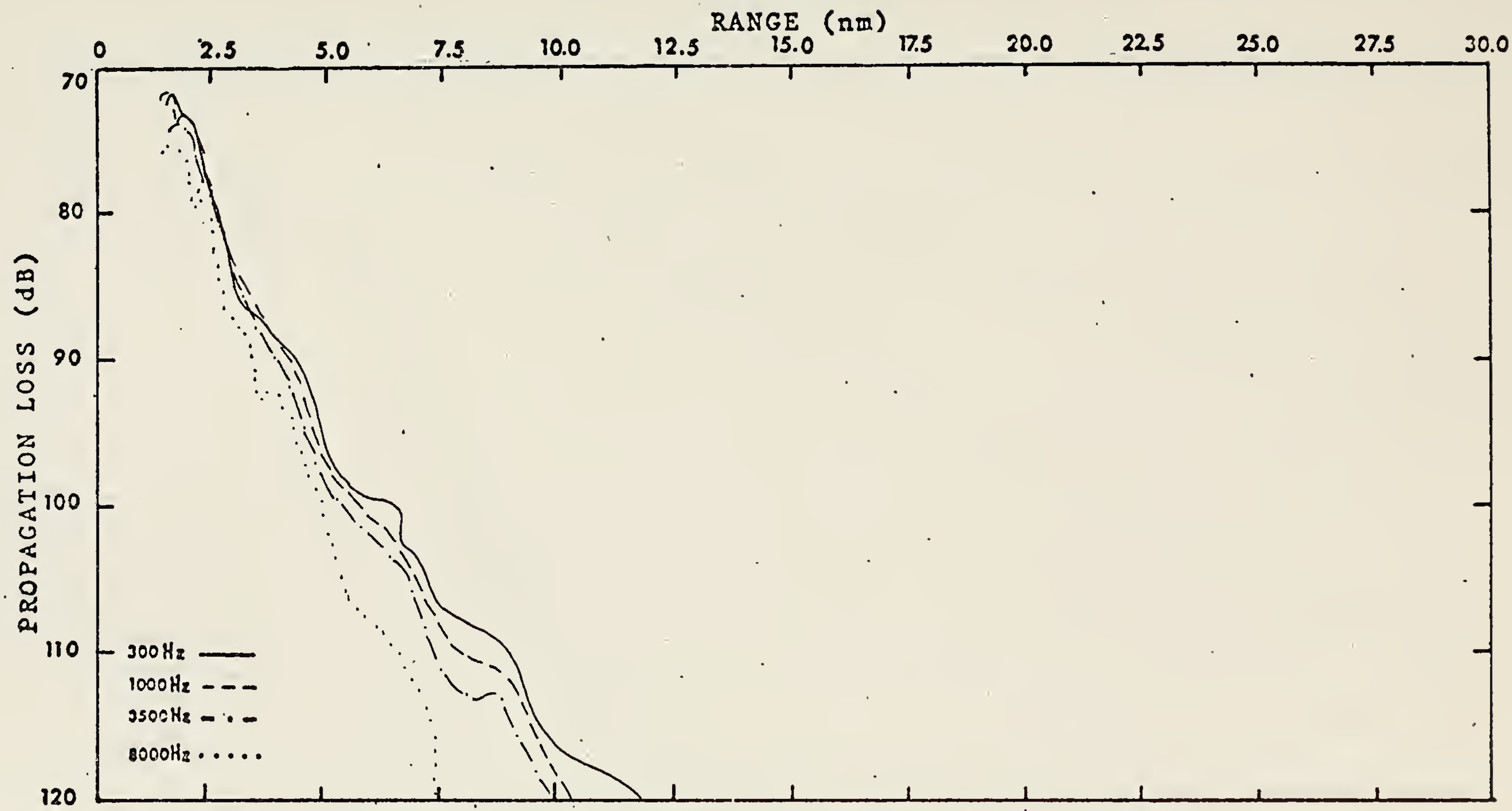

Figure B-13. Propagation loss profile for area I during summer. Source at 60 ft, receiver at 60 ft.

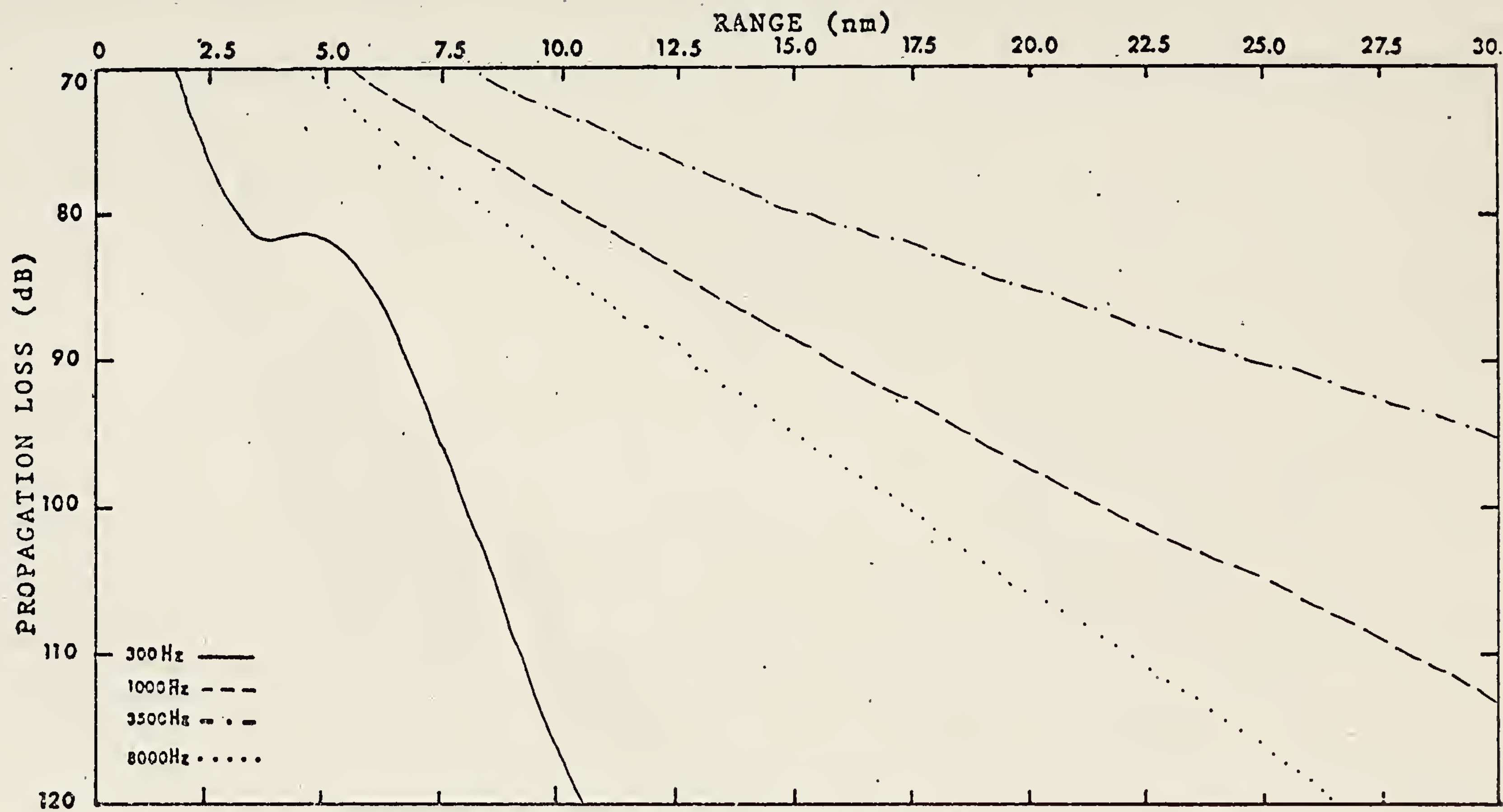

Figure B-14 . Propagation loss profile for area II during summer. Source at 60 ft, receiver at 60 ft.

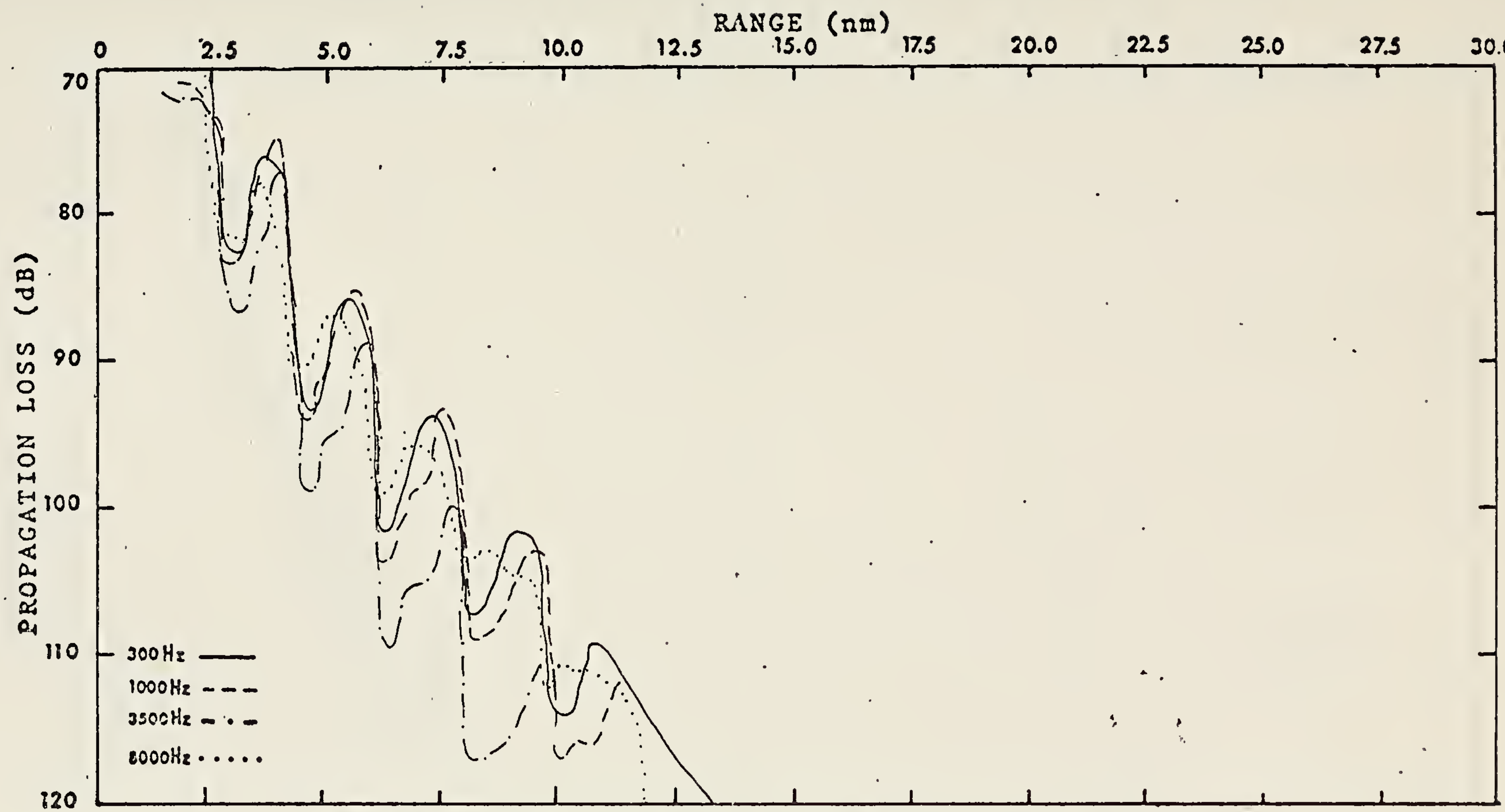

Figure B-15. Propagation loss profile for area III during summer. Source at 60 ft, receiver at 60 ft.

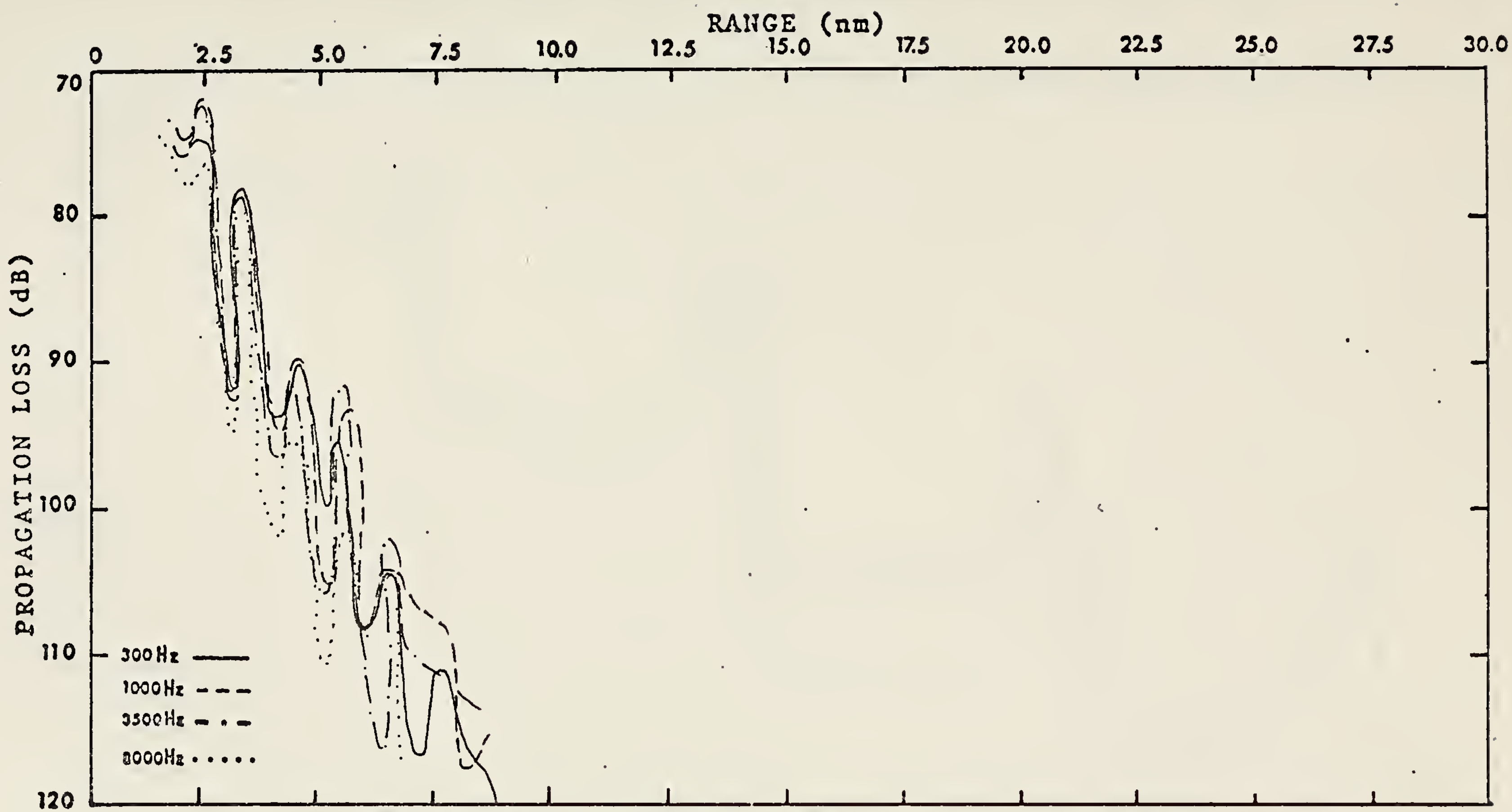

Figure B-16. Propagation loss profile for area IV during summer. Source at 60 ft, receiver at 60 ft.

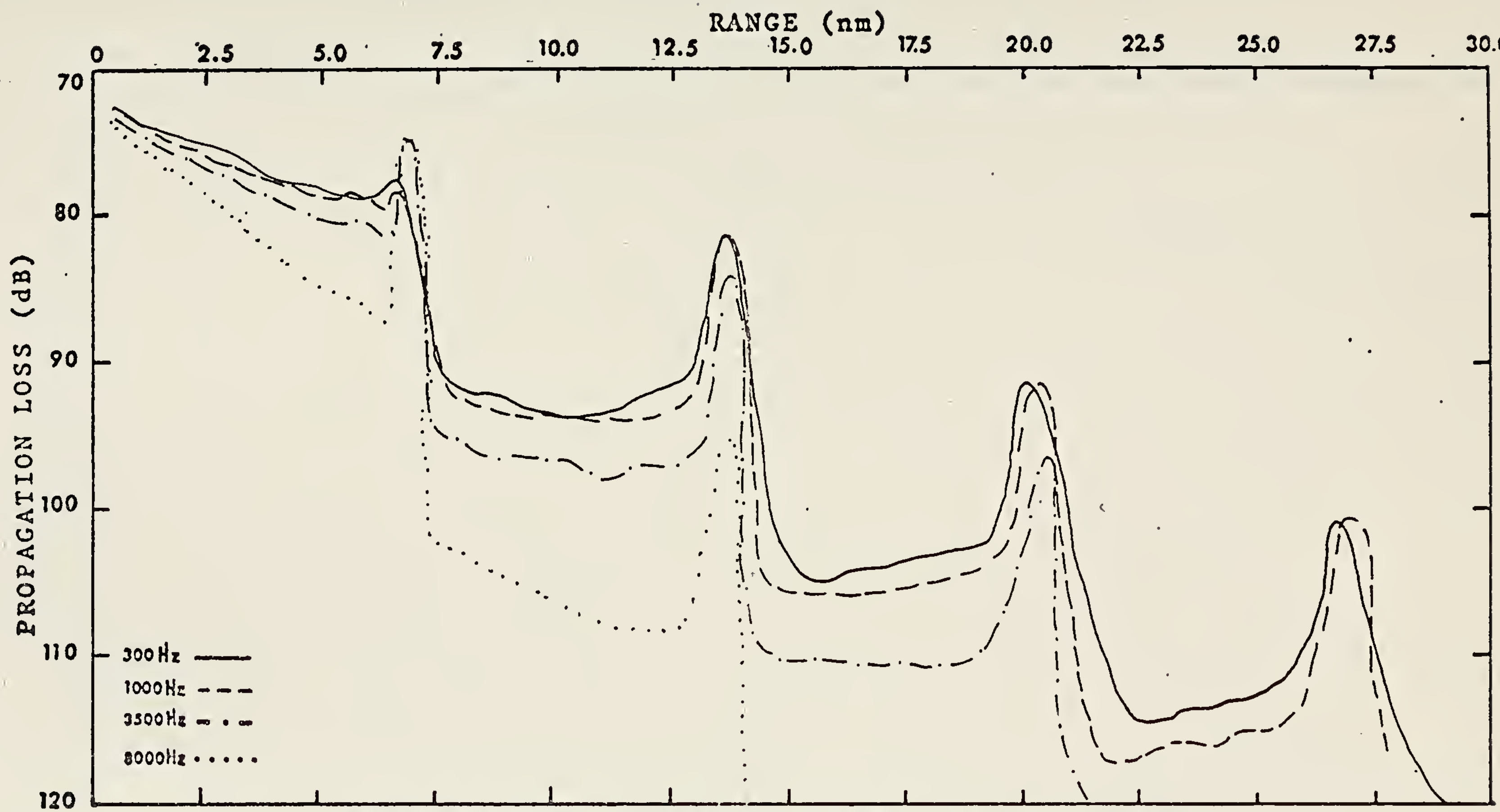

Figure B-17. Propagation loss profile for areav during summer. Source at 60 ft, receiver at 60 ft.

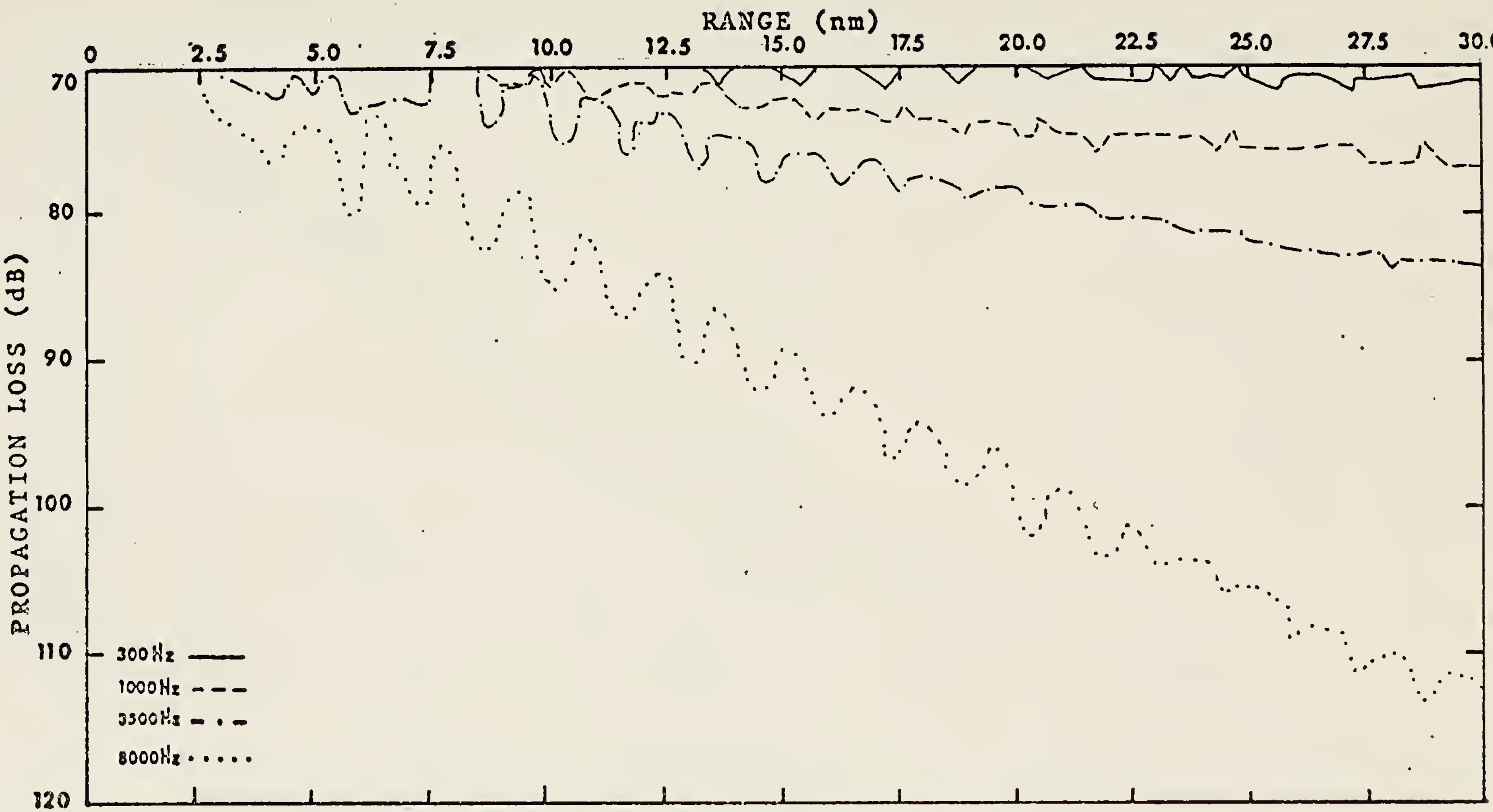

Figure B-18. Propagation loss profile for area V during summer. Source at 300 ft, receiver at 300 ft.

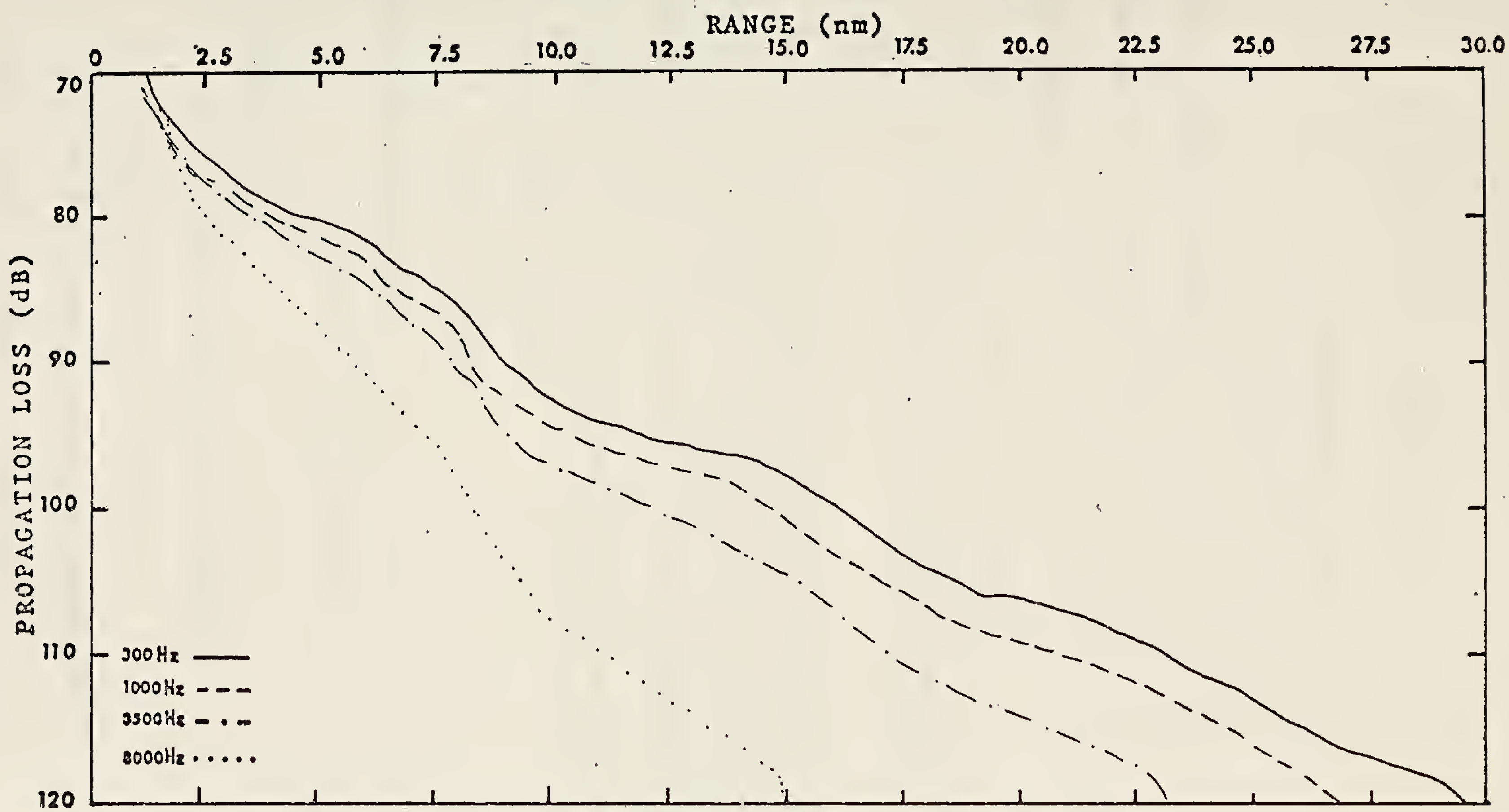

Figure B-19. Propagation loss profile for area v during summer. Source at 60 ft, receiver at 300 ft.

APPENDIX C

FIGURE OF MERIT

Passive February and July

FOM = SL - NL - RD + DI = TL

Source Level

SL = 52 db for a typical nuclear submarine

SL = 55 db for a typical snorkeling diesel submarine

Noise Level

Considering air dropped sonobuoys, the noise level is primarily a function of ambient noise. The Wenz Curves provide an approximate ambient noise level. As the Gulf is an area of heavy shipping and has an average sea state of 2, the following values were obtained

NL = - 30 db for 300Hz

NL = - 40 db for 1000Hz

Recognition Differential

RD = 0 for 50% probability of detection

Directivity Index

DI = 0 for omnidirectional passive sonobuoy

FOM = 82 db for 300Hz, nuclear sub.

FOM = 85 db for 300Hz, snorkeling diesel sub

FOM = 92 db for 1000Hz, nuclear sub

FOM = 95 db for 1000Hz, snorkeling diesel sub

Active February and July

FOM = SL - NL + TS + DI - RD = 2 TL

Source Level

SL = 145 for 3500Hz of typical sonar

= 130 for 8000Hz of typical sonar

Noise Level

The NL for a destroyer operating at 16 kts is approximately -35 db (re 1 μ bar) at 1 yard.

NOTE: NL is difficult term to determine in the active equation as it is composed of three terms; self noise, ambient noise, and reverberation level. The main difficulty lies in the reverberation term as knowledge is lacking on reverberation levels expected in the Persian Gulf. As a result, the FOM may be too large and the resulting detection ranges overly optimistic.

Target Strength

TS = 10 db for a bow or stern aspect

Directivity Index

DI = 25 db for a typical hull mounted sonar

Recognition Differential

RD = 0 db for 50% probability of detection

FOM = 195 db for 3500Hz

FOM = 180 db for 8000Hz

APPENDIX D

Sound speed profiles for winter and summer. Each profile is for a particular area of acoustic similarity. (Refer to Figs. 19 and 20)

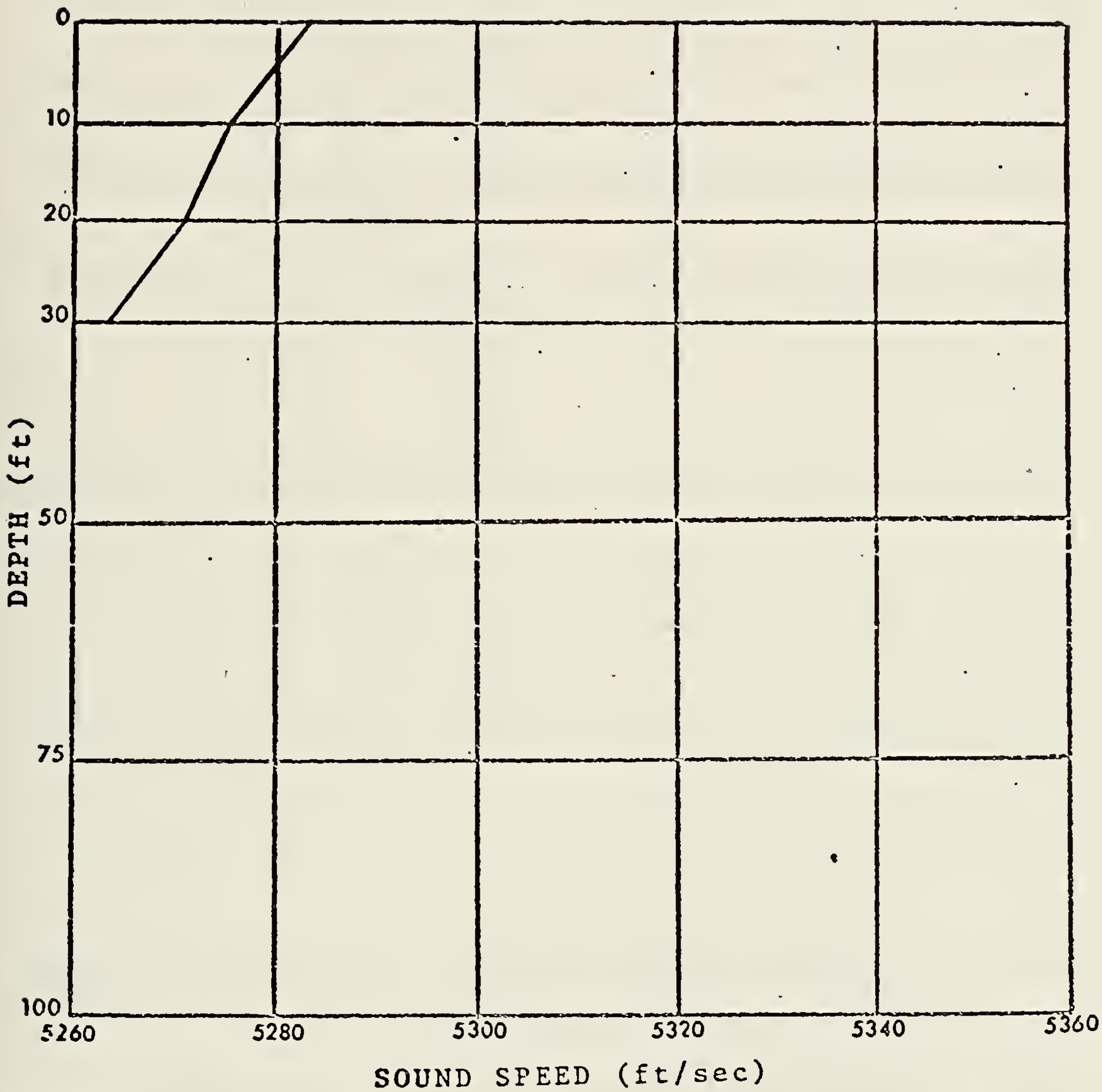

Figure D-1 . Sound speed profile, winter, area I

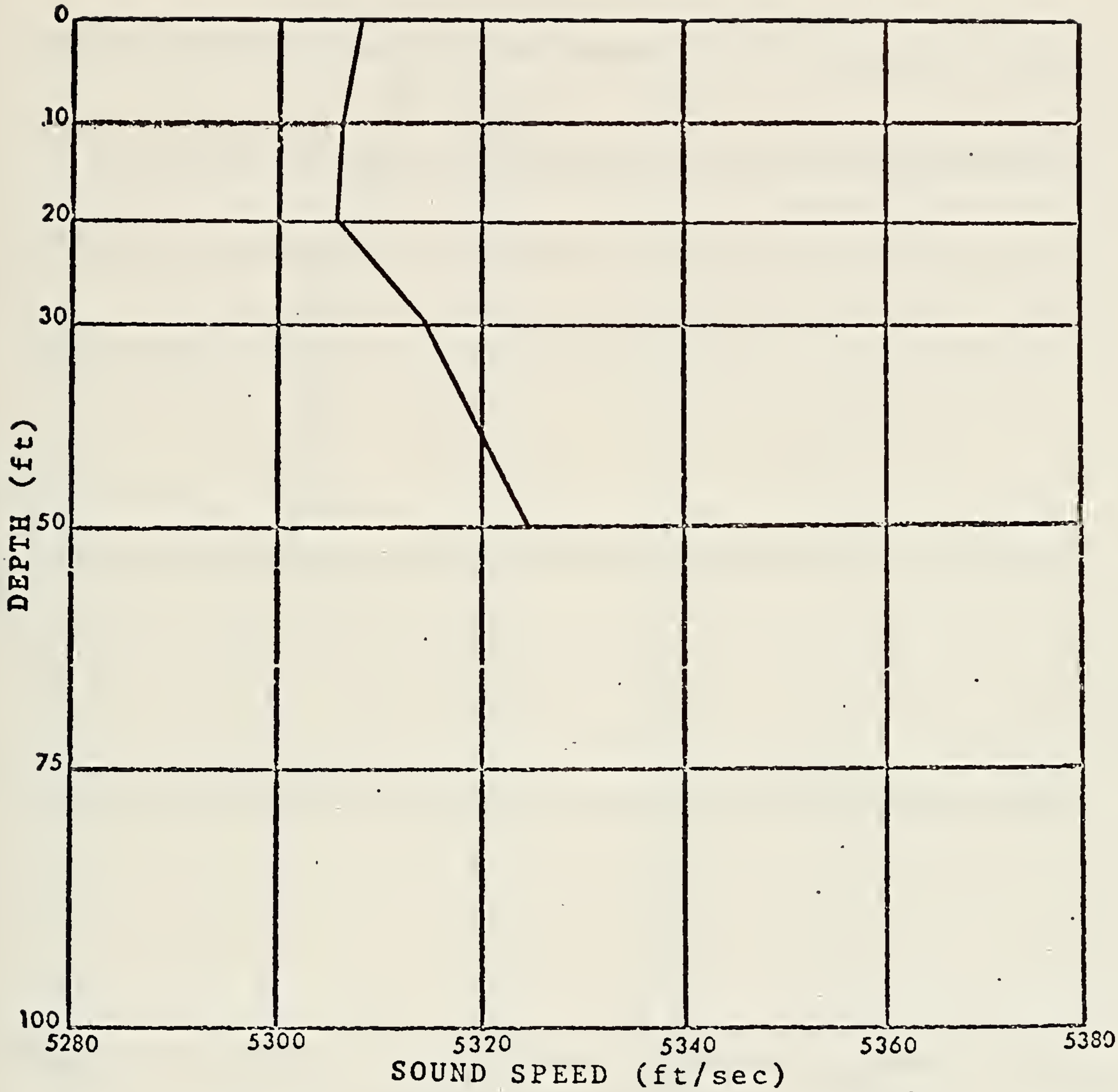

Figure D- 2 . Sound speed profile, winter, area II

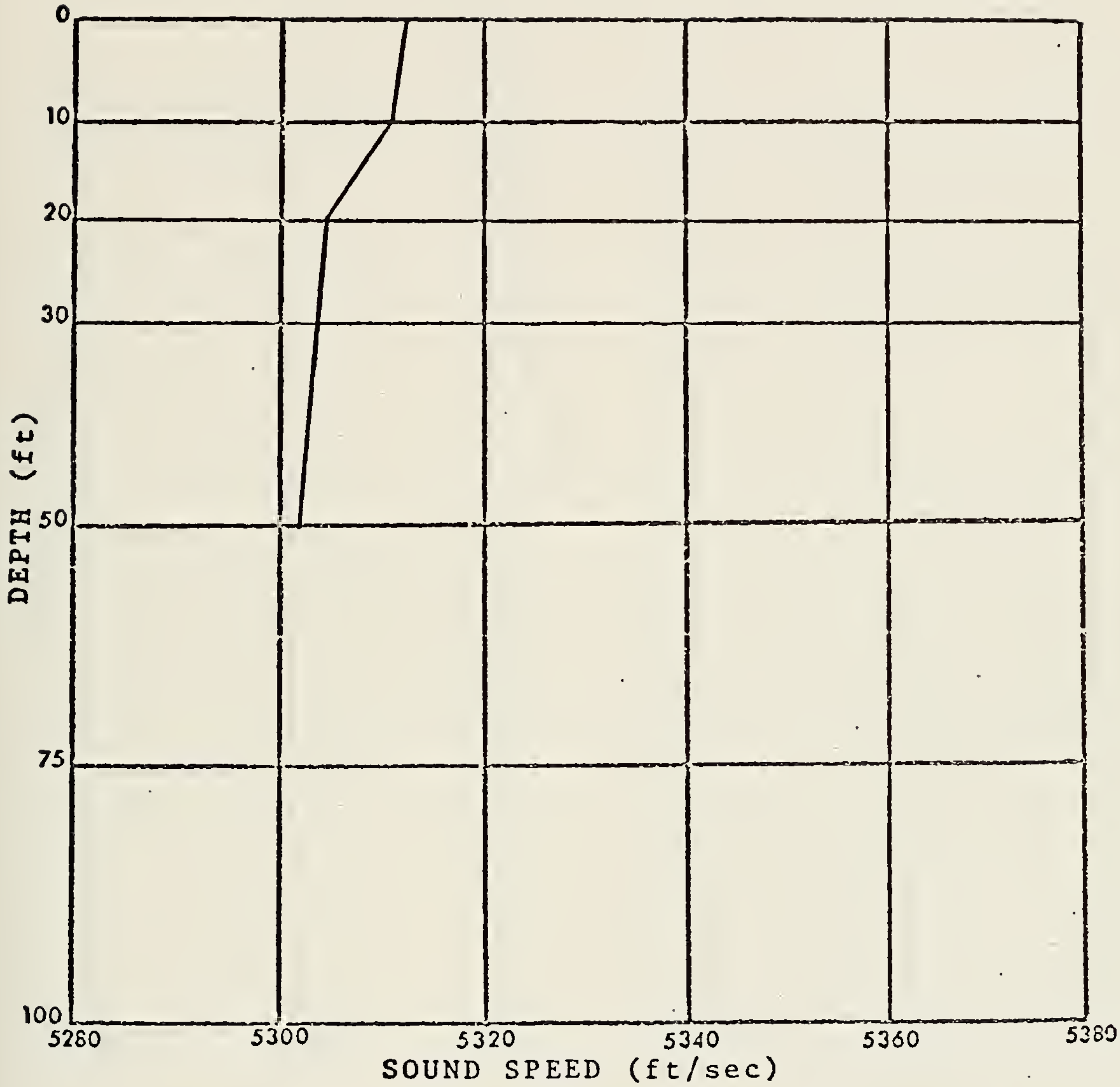

Figure D-3 . Sound speed profile, winter, area III

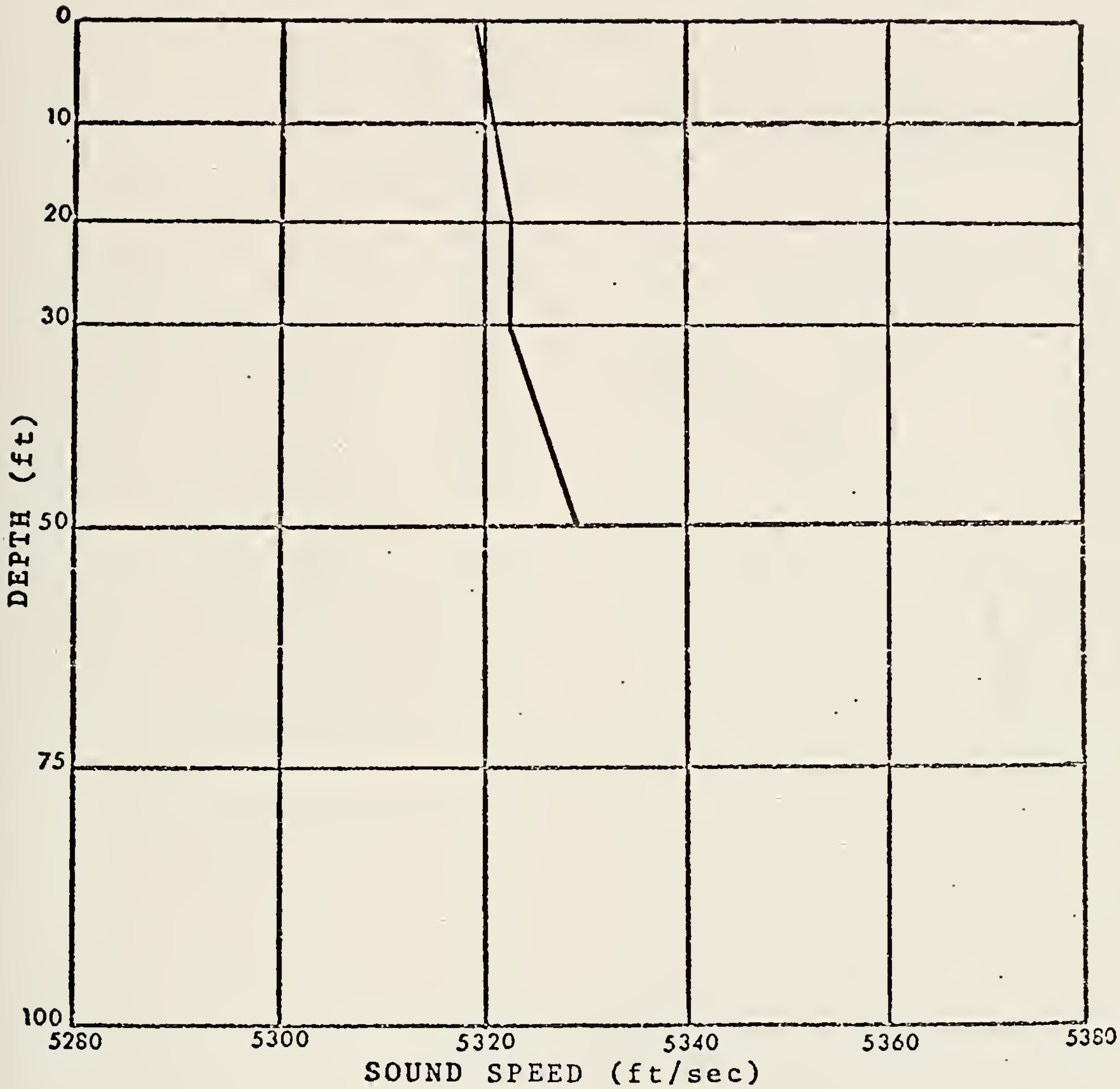

Figure D-4 . Sound speed profile, winter, area IV

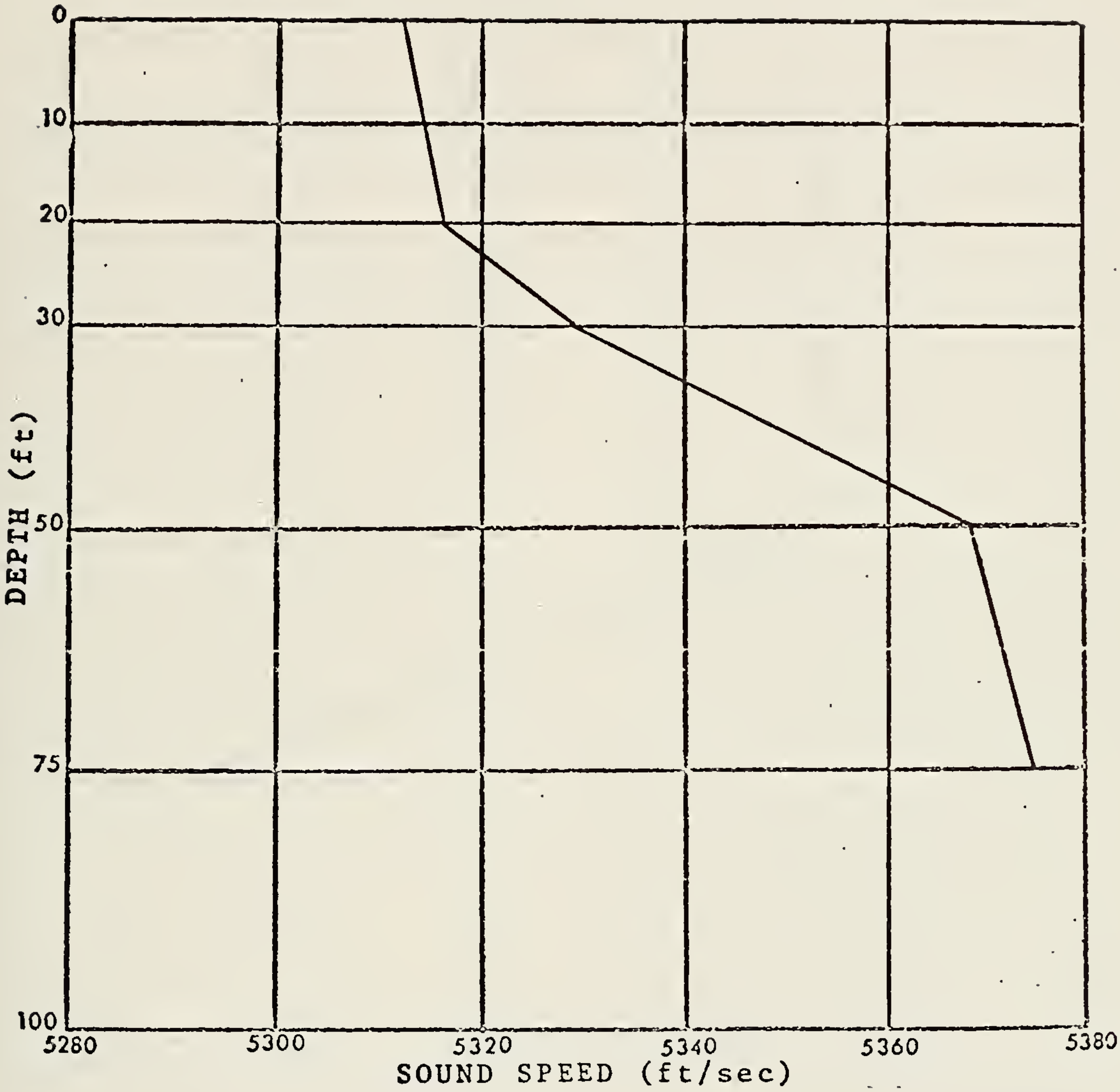

Figure D-5 . Sound speed profile, winter, area v

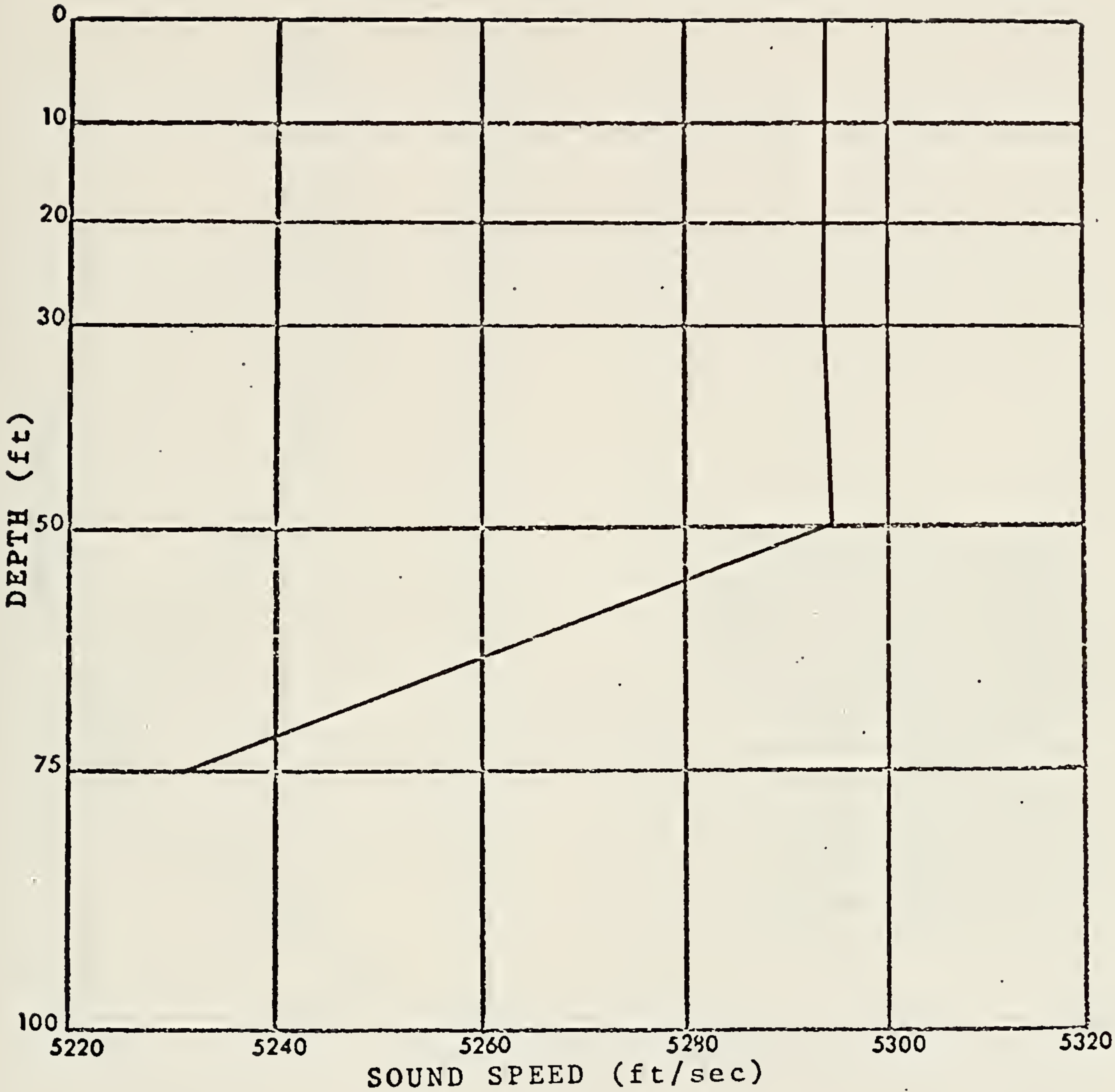

Figure D-6 . Sound speed profile, winter, area VI

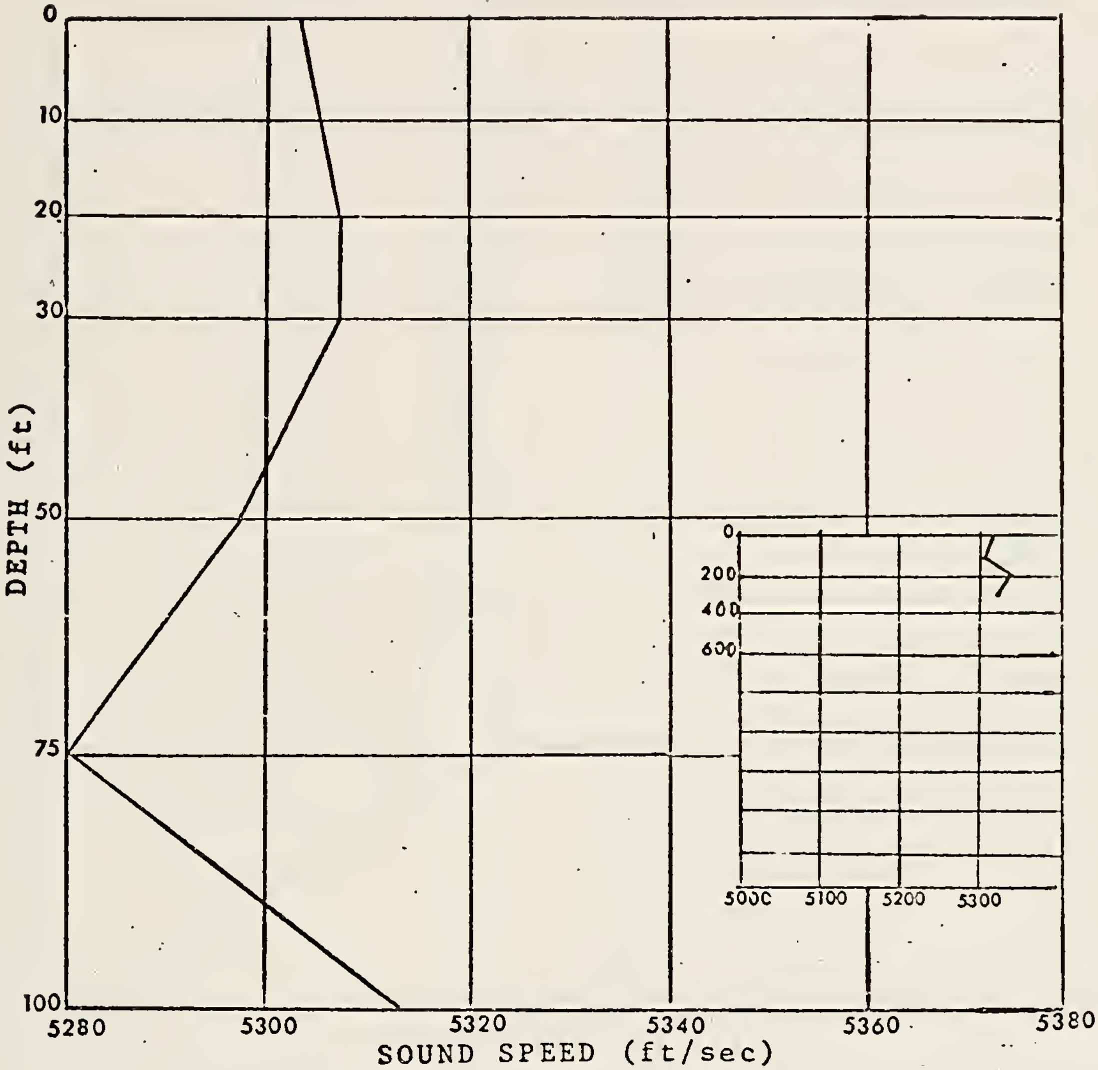

Figure D- 7 . Sound speed profile, winter, area VII

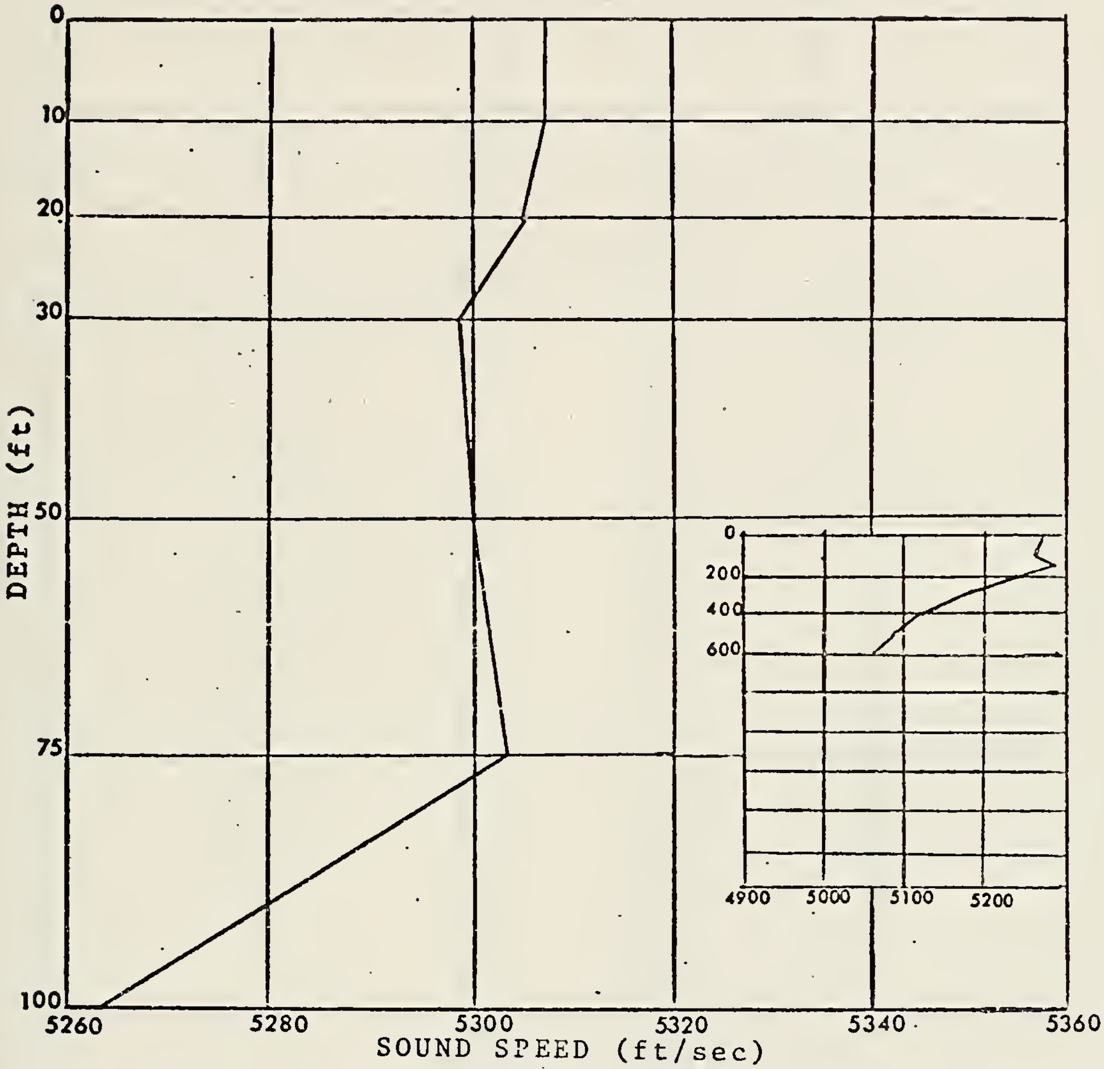

Figure D- 8 . Sound speed profile, winter, area VIII

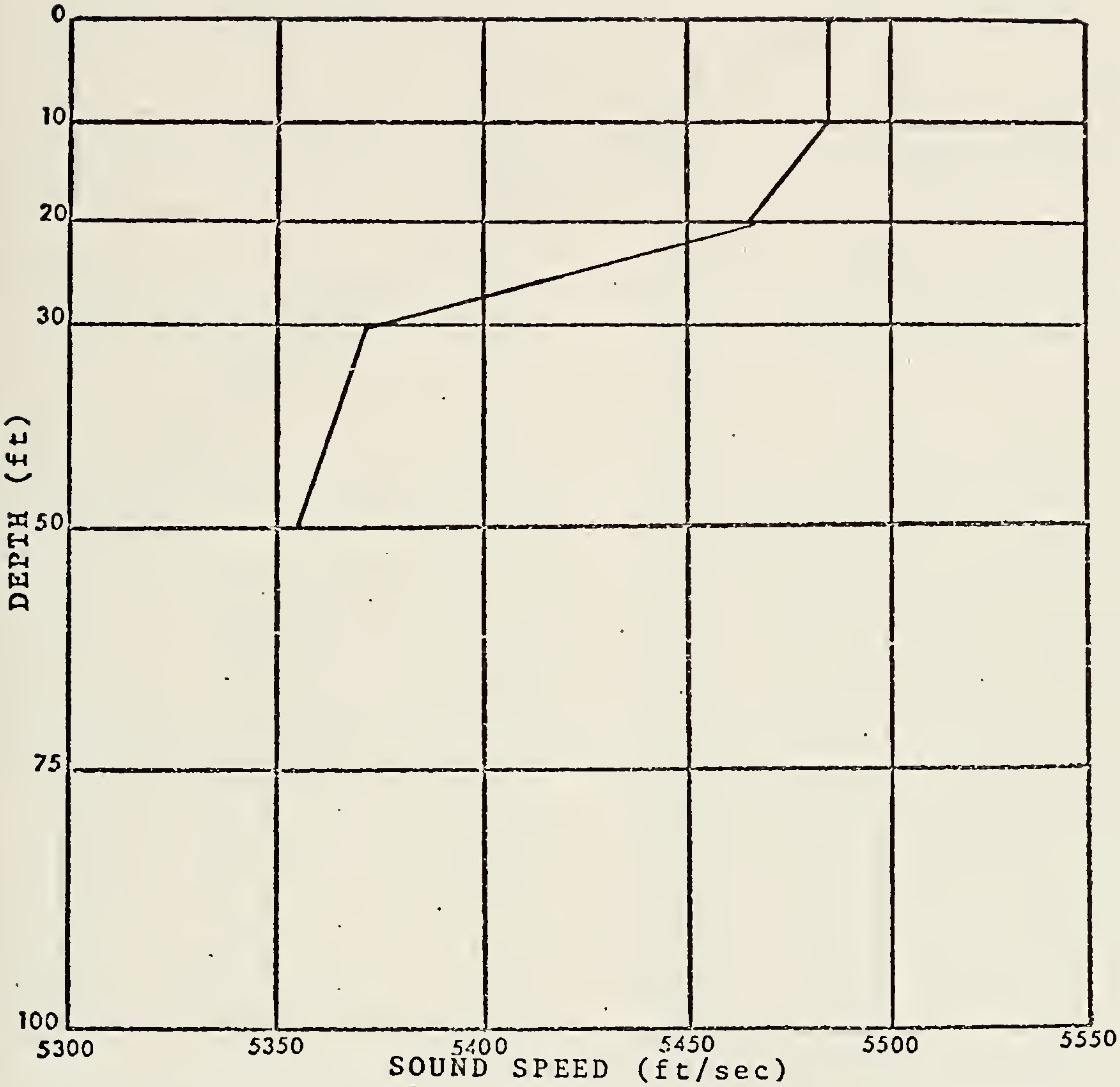

Figure D- 9 . Sound speed profile, summer, area 1

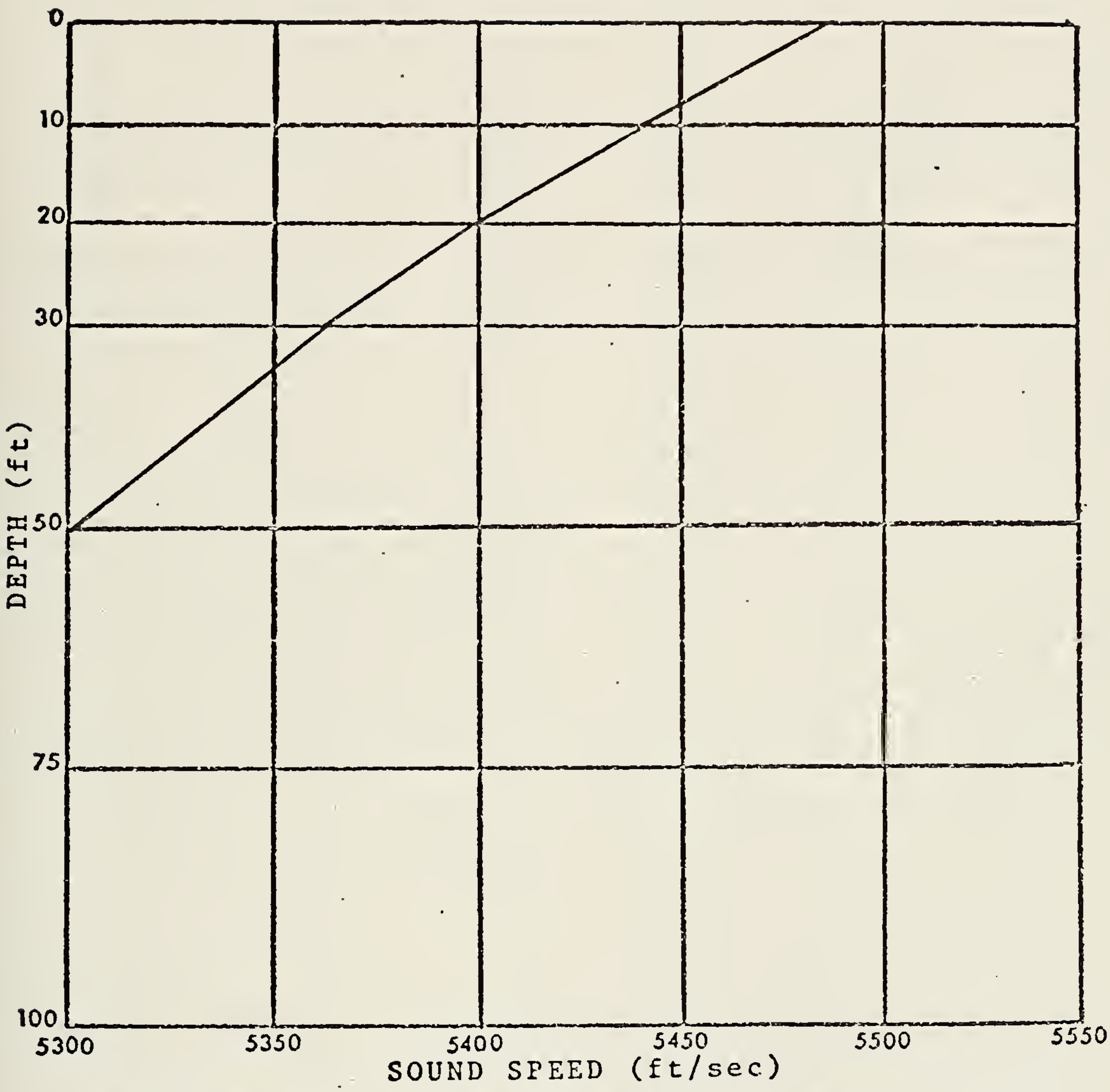

Figure D-10. Sound speed profile, summer, area II

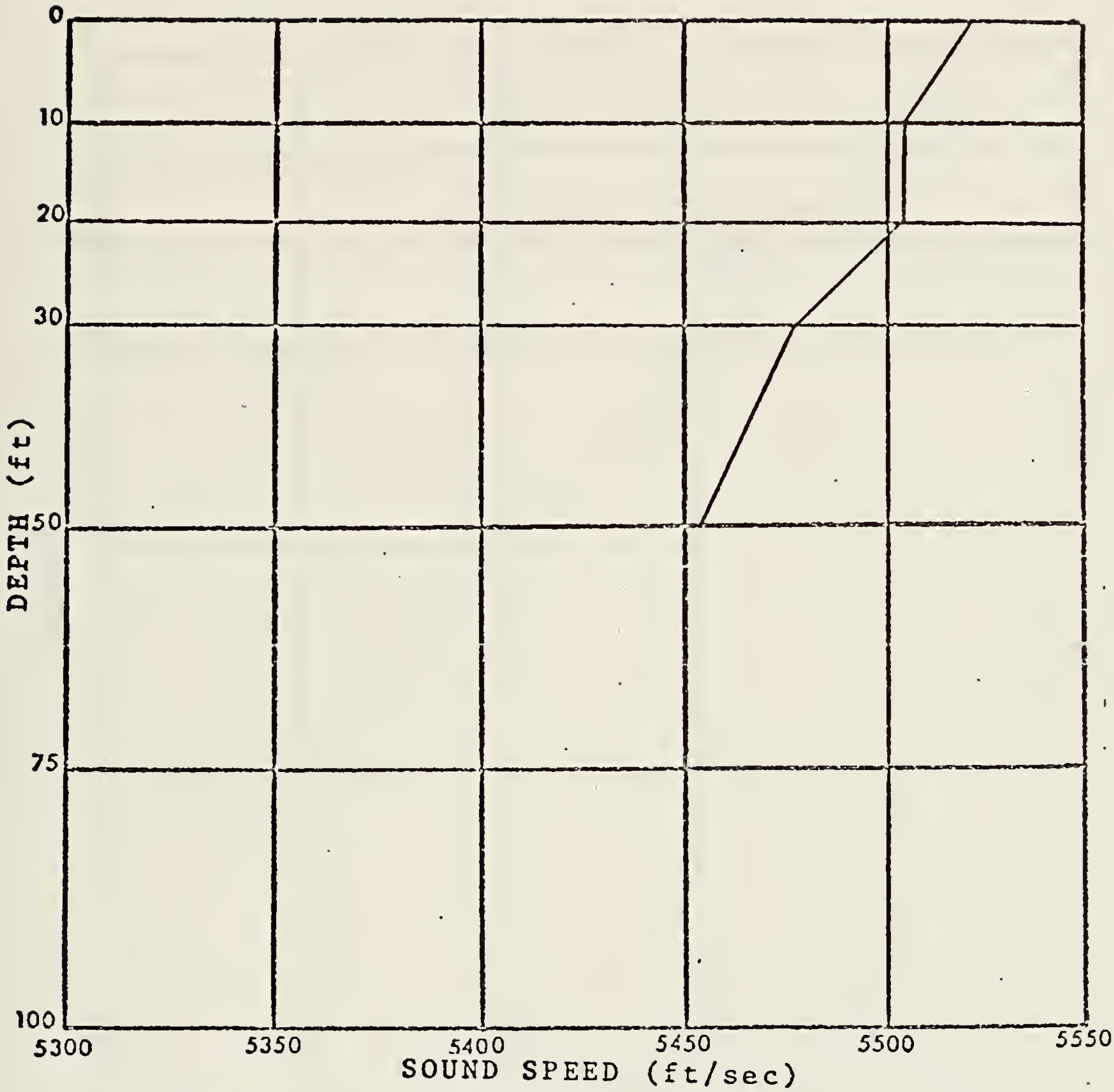

Figure D-11. Sound speed profile, summer, area III

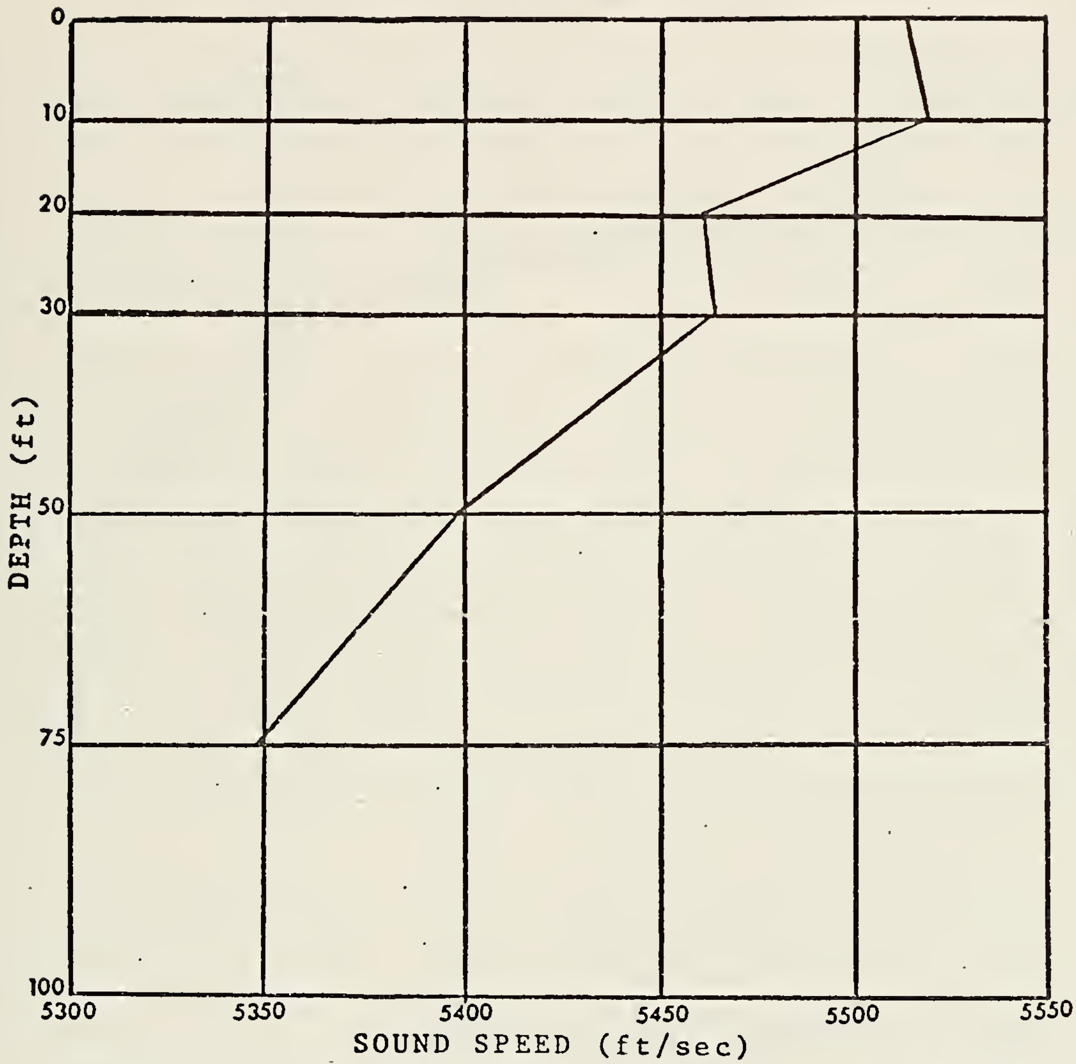

Figure D-12. Sound speed profile, summer, area IV

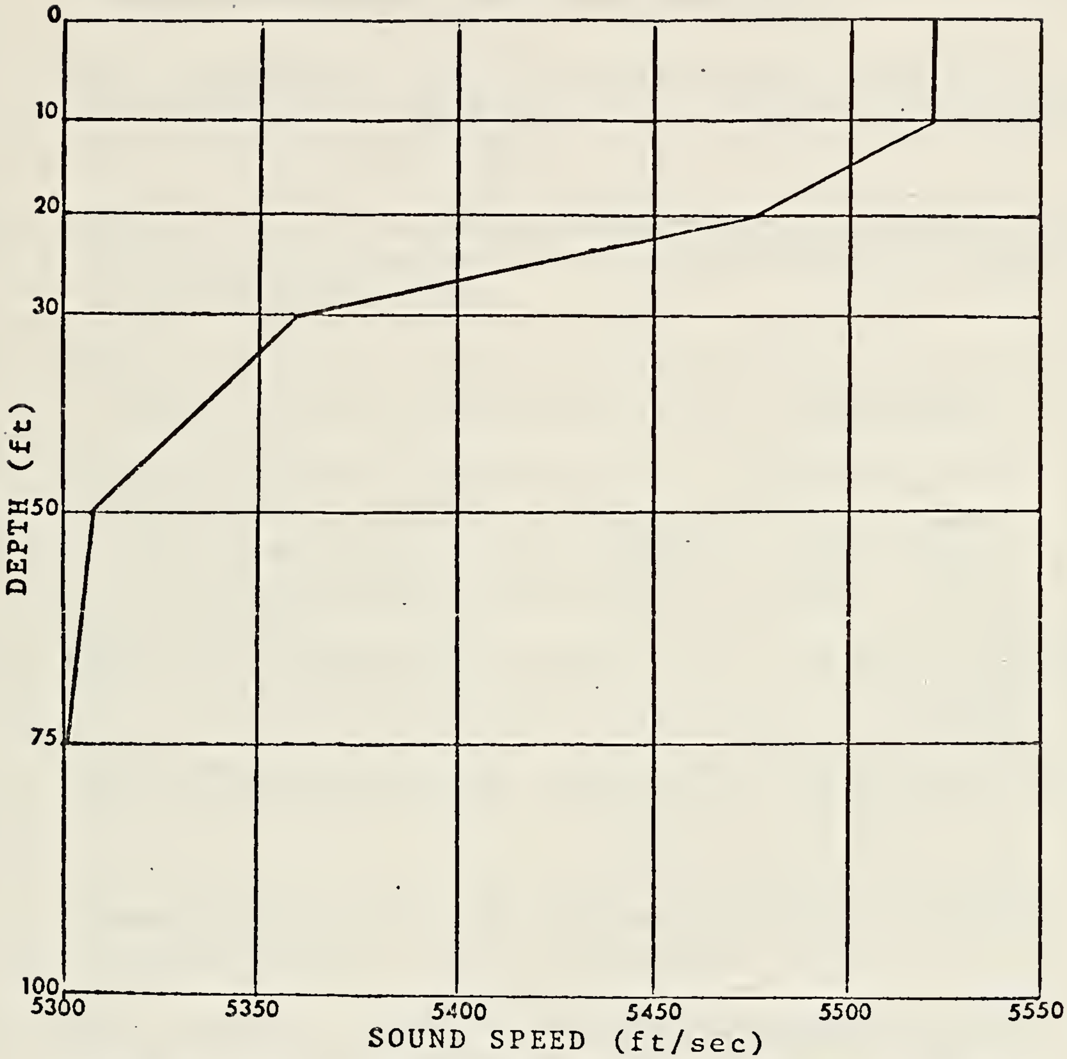

Figure D-13. Sound speed profile, summer, area v

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